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THE STOCK OF ALKALINE ROCKS NEAR LIBBY, MONTANA

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ABSTRACT

A stock of alkaline rocks 2½ by 3½ miles in outcrop is described from seven miles northeast of Libby, Montana. The oldest and chief rock of the stock is a pyroxenite that commonly is made up mostly of pyroxene with much apatite, some garnet and magnetite, and a variable amount of biotite. Parts of the pyroxenite are made up almost entirely of biotite, now altered to vermiculite. Nepheline syenite with some syenite is younger than the pyroxenites, and small dikes of granite were the latest intrusions.

Hydrothermal action has altered the pyroxenite in narrow veins and larger bodies to a fibrous amphibole. It has also replaced most of the nepheline of the nepheline syenite to muscovite, less commonly to zeolites or albite, and has introduced abundant aegirite and titanite in parts of the syenite.

Veins, made up chiefly of quartz and carrying next the wall rock abundant vanadiferous aegirite, sulphides, strontianite, and celestite, cut the pyroxenite, which is altered next the veins to fibrous amphibole.

INTRODUCTION

The stock described in this paper lies in Lincoln County, northwestern Montana, about 7 miles northeast of Libby. It occupies most of the lower drainage basin of Rainy Creek, is about 3½ by 2½ miles in horizontal dimensions, and underlies an area of about 6 square miles. It intrudes the slate, quartzite, and limestone of the Belt series, of Algonkian age. The intrusive mass shows no evidence of metamorphism, and the Belt rocks were folded and dynamically metamorphosed before the intrusion. No upper limit for the age of the intrusion can be given.

[1] Published with the permission of the director of the United States Geological Survey.

The rocks of the stock, especially the pyroxenite, are much less resistant to weathering and erosion than the Belt rocks; the stock therefore underlies a basin, and the Belt rocks form mountains that surround the stock and rise sharply a thousand feet or more above it.

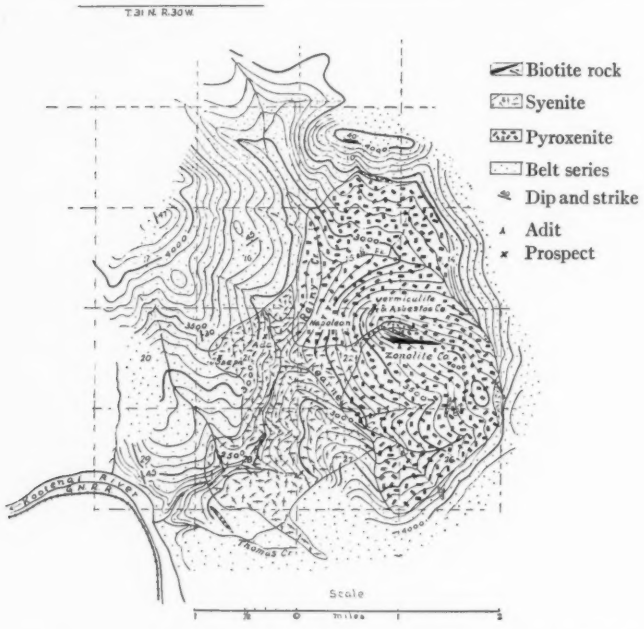

FIG. 1.—Reconnaissance geologic map of the Rainy Creek stock near Libby, Montana.

Glacial débris has been deposited in the basin in large amount and has covered much of the stock.

A pyroxenite rich in apatite makes up the northeastern two-thirds of the stock and was the earliest of the intrusive bodies. It is a medium- to coarse-grained rock, in most places made up three-fourths of diopside-hedenbergite. It usually contains abundant apatite, some magnetite and garnet, and more or less biotite. Locally the rock is nearly pure biotite.

The pyroxenite was followed by syenite and nepheline syenite,

which probably represent several separate phases of intrusion and together make the southwestern third of the stock. These rocks are much altered and contain secondary muscovite, vermiculite, aegirite, titanite, and other minerals. The syenitic rocks were followed by a few small dikes of granite, which are mostly confined to the area of Belt rocks, but also cut the syenite and pyroxenite.

In the following pages both authors have collaborated in describing the field relations and occurrence of the rocks, but the determinations and discussion of the mineralogy and petrology are the work of Mr. Larsen.

QUARTZ LATITE PORPHYRY DIKES

Small dikes of quartz latite porphyry are common in the Belt rocks, but none were seen cutting the pyroxenite or syenite of the stock, and they are believed to be considerably older than the stock, as they show much more metamorphism. The rock of these dikes is rather dark gray and carries about 20 per cent of white plagioclase phenocrysts as much as 5 millimeters long in a dark aphanitic matrix. The groundmass is made up of quartz, orthoclase, plagioclase, and alteration products in grains about 0.1 millimeter in diameter. No dark mineral remains. Abundant secondary epidote, sericite, chlorite, calcite, and biotite are scattered through the groundmass, included in the phenocrysts, or aggregated in bunches. Some brown allanite that is probably secondary is also present.

PYROXENITE

The pyroxenite is a soft rock that offers little resistance to weathering and erosion, and hence it forms the lower, gentler slopes of the Rainy Creek basin. There is a rather sharp change in slope, with rocky ridges, where the pyroxenite gives place to the Belt rocks or to the syenite. Its gentle rolling slopes are mostly covered with more or less glacial débris, and it gives no rocky outcrops and very few weathered outcrops. Even the soil of the area it underlies is in few places characteristic, and for a study of the rock one must depend mainly on prospect pits, which are not numerous. Hence the details of the distribution of the rocks must be based on the topography, and no detailed study of the variation of the rock from place to place can be made. The rock is everywhere weak and in most places is so

friable that it can be crushed to a sand by squeezing in the hand. In mining operations holes for blasting are commonly bored in this rock with an ordinary steel-bitted auger. In only a few of the longer tunnels where the rock is low in mica can satisfactory hand specimens be collected.

The pyroxenite ranges in size of grain from less than a millimeter to several decimeters. In some places grains of very different size are mixed together, but as a rule any particular body of rock is fairly even grained, though streaks and patches of coarse and fine rock are common. The distribution of the textural types shows no law or system; in some places fairly large bodies are of rather uniform texture, and in others coarse and fine rock are mixed in a single hand specimen; in some places the rocks of different texture have sharp contacts, and in others the contacts are gradational. There is little relation between coarseness of grain and mineral composition.

Mineralogically the pyroxenite ranges from a nearly pure pyroxene rock to a nearly pure biotite rock. Apatite, rich in fluorine, (n about 1.639) commonly makes up from 7 to 10 per cent of the pyroxene-rich rocks, though locally it is present in only small amount. This large body of rock is therefore one of the richest in apatite that has been described. Apatite is less abundant in the biotite-rich rock and is almost entirely absent in some of the rock that is nearly pure biotite. Microcline-microperthite is present in small amounts in the biotite-rich rocks, and in places it forms angular fragments between the large mica plates. It makes up as much as 15 per cent of some rocks and appears to be more abundant in the rocks made up mostly of biotite, but containing a little pyroxene, than in the rocks that are entirely lacking in pyroxene.

Titanite is rare or absent in most of the pyroxenite, but a few specimens of the pyroxene-rich rock carry more or less titanite, and one small body in a prospect pit near the northern boundary of the pyroxenite, in the saddle at the head of the east fork of Rainy Creek, contains approximately 40 per cent of titanite, a little apatite, 10 per cent of magnetite (or ilmenite), and 50 per cent of pyroxene. Magnetite (or ilmenite) as an interstitial mineral makes up from 3 to 12 per cent of most of the pyroxenite that is low in biotite, but it is entirely absent in some of such rocks, and it is absent or occurs

only in small amount in nearly all the rocks that contain more than 20 per cent of biotite.

Brown garnet is rarely an accessory in the pyroxene-rich rock, and a single small bunch from the Napoleon claim, sent to the writers by the owner, Mr. Thomas (since deceased), contains about 5 per cent of an iron garnet ($n=1.885$), probably a titaniferous andradite, as an interstitial mineral, with 80 per cent of pyroxene, 6 per cent of biotite, 7 per cent of apatite, 2 per cent of magnetite (or ilmenite), and a little titanite.

A remarkably large mass of biotite rock (now altered to vermiculite) occurs in the ridge between Rainy and Kearney creeks on the south slope near the crest. It presents no natural exposures, but its outcrops and the slope below are mantled with a yielding slippery soil composed chiefly of mica-like flakes. As partly shown by a number of shallow pits and a tunnel constructed by the Zonolite Company, this body appears to be at least 100 feet wide and 1,000 feet long. It trends eastward and stands about vertical. At a depth of 100 feet, the greatest depth attained by the workings, the mass appears unchanged in form or composition. Difficulty was experienced in preventing the material from caving and closing the underground workings. A drift parallel to the body was run in the pyroxenite of the south wall, from which openings for chutes were made at intervals. From these chutes, when open, the vermiculite runs or falls freely without being blasted or mechanically loosened, and it continues to run until the natural stope thus started reaches the surface. The grains of the biotite rock (vermiculite) range in diameter from a millimeter to a decimeter. Moderately coarse material is the more abundant, and the different textural parts are erratically distributed. Its contacts with the normal pyroxenite range from sharp to gradational through a zone a foot or more wide.

A short distance northwest of the occurrence just described several smaller bodies of unmixed biotite rock (vermiculite) are exposed in open cuts and tunnels of the Vermiculite and Asbestos Company. These bodies crop out on a northwest slope at a level 300 or 400 feet lower than the outcrop of the larger mass, and the outcrops are, as usual, covered by the surface mantle. The longest tunnel penetrates six bodies of unmixed vermiculite that range from

1 to 4 feet in width. They are of lenslike or pinching and swelling tabular form, and most of them are definitely separated from the pyroxenite by slip or fault planes. They are prevailingly fine grained but include coarse material in places. Analyses of representative samples of two of these bodies show them to contain, in round figures, 98 per cent of vermiculite, the remainder being chiefly apatite. The greatest depth attained by underground workings in the area considered is about 150 feet. To this depth the alteration to vermiculite is complete, no biotite remaining. Apparently the change is entirely of deep-seated or hydrothermal origin, the effects of weathering being confined to a zone extending but a few feet below the present surface.

Exposures are too scattered to permit a good estimate of the proportion and distribution of the types of the pyroxenite, but so far as could be judged the pyroxene-rich rock with about 10 per cent of apatite, 10–20 per cent of biotite, and a little magnetite is prevalent, though rock much richer in biotite is common. In the workings of the Vermiculite and Asbestos Company several good-sized masses of pyroxenite are exposed that contain from 30 to 84 per cent of biotite (vermiculite). As much as 15 per cent of apatite occurs in some of the poorer of these masses.

The pyroxene is chiefly pale green in section, but irregular borders of the grains, especially next to apatite, and irregular veinlets through the grains are darker green. The dark-green variety is no doubt a reaction product and may be due to moving hydrothermal solutions, probably after the complete crystallization of the rock. The pale-green pyroxene is a diopside with a little acmite molecule and about 10 per cent of hedenbergite, as indicated by the following optical properties: Opt., +, 2V large, extinction $Z \wedge c = 43°$, $\alpha = 1.685$, $\beta = 1.699$, $\gamma = 1.719$. The darker-green pyroxene that forms the borders is probably richer in hedenbergite as indicated by the following properties: $Z \wedge C = 42°$, $\beta = 1.707$.

A calculation of the approximate composition of the pyroxene by deducting from the rock analyses the apatite, ore, biotite, etc., found by the Rosiwal analysis gave its composition as acmite, 7 per cent; $CaO.MgO.2SiO_2$, 73 per cent; $CaO.FeO.2SiO_2$, 20 per cent, with a small excess of Al_2O_3 and Fe_2O_3 and a slight deficiency of SiO_2.

A specimen of typical fresh coarse-textured pyroxene-rich rock from the Napoleon tunnel, analyzed by George Steiger in 1912, has the composition shown in Table I.

A Rosiwal determination of several sections from the analyzed specimen gave consistent and satisfactory determinations for the

TABLE I

ANALYSES OF PYROXENITE AND OF BIOTITE

	1*	2†
SiO_2	37.47	40.6
Al_2O_3	2.86	14.1
Fe_2O_3	11.77	2.3
FeO	7.83	1.7
MgO	10.12	27.0
CaO	21.68	.....
Na_2O	.47	1.2
K_2O	.93	8.2
H_2O-	.27	3.2
H_2O+	.73	.....
TiO_2	1.07	.....
ZrO_2	None	.....
CO_2	.36	.....
P_2O_5	4.33	.....
S	.04	.....
F	.36	1.5
V_2O_3	.12	.....
MnO	.16	.....
BaO	.06	.....
SrO	.14	.....
	100.77	.....
Less O	.15	.....
	100.62	.....

* Apatite pyroxenite from Napoleon tunnel. Specific gravity, 3.417, as measured on a hand specimen.

† Iron-poor biotite, to give about the composition of the fresh biotite rock.

apatite and fairly good results for magnetite and ilmenite, but the biotite was clearly lower than shown by the hand specimen, and the calcite and garnet were very unevenly distributed. The norm as calculated by the quantitative classification and the mode are shown for comparison in Table II.

Clearly the leucite, nepheline, and anorthite and part of the magnetite of the norm are in the pyroxene, biotite, and garnet of the mode.

The biotite rock is everywhere more or less completely altered

to vermiculite; hence no analysis of it was made. However, the composition is that of an iron-poor biotite, as the rock is nearly unmixed with other minerals. An approximate analysis of such biotite is shown in column 2 of Table I to indicate the composition of the

TABLE II

NORM AND MODE OF APATITE PYROXENITE FROM NAPOLEON TUNNEL

Norm		Mode	
Leucite	4.36	Biotite	5
Nepheline	2.27	Diopside	74
Anorthite	3.06	Ore	10
Diopside	59.81	Apatite	10
Ilmenite	1.98	Garnet	1
Magnetite	17.40	Calcite	Little
Apatite	10.42	Titanite	Little
Calcite	.90		

Classification: (IV) V. 2. 1. 3. 2.

biotite rock and for comparison with the pyroxene rock. The biotite rock might be called a glimmerite.

On comparing the pyroxene-rich rock with the biotite rock it is clear that the two have about the same amounts of SiO_2, but the biotite rock has much more Al_2O_3, MgO, and K_2O, somewhat more Na_2O,H_2O, and F, much less CaO, and less Fe_2O_3, FeO, and P_2O_5. The differentiation is clearly mineralogical.

NEPHELINE SYENITE

Nepheline syenite, fresh enough to classify with assurance, was found only as a single dike or sill, a few feet across, striking about northwest in the Belt rocks, extending across the ridge between Thomas and Rainy creeks, and crossing the ridge about 0.2 mile east of the southwest corner of Sec. 28, T. 31 N., R. 30 W.

The freshest rock was found in a prospect just north of Thomas Creek. It is a light-gray to brownish-gray rock varying irregularly from fine- to coarse-grained, in which some of the coarser grains have diameters as great as 2 centimeters. The texture is seriate porphyritic. The rock is composed chiefly of nepheline, albite, and microcline in nearly equal amounts, and in addition contains small amounts of aegirite and a very little apatite and magnetic iron ore besides secondary fluorite, cancrinite, natrolite, and other zeolites. In the

hand specimen the rock is seen to be made up chiefly of white feldspar. Part of the albite is in poorly bounded laths, of which some are several centimeters in length, but most are much smaller. The microcline occurs in less regular masses. The nepheline is present in irregular crystals, the largest several centimeters across, and stands out prominently on account of its brownish color and greasy luster in contrast to the porcelain-like feldspar. The aegirite occurs in long needles, which are flattened parallel to the front pinacoid. A few small areas of purplish fluorite can be recognized, as well as those of yellow cancrinite and grains of black iron ore. A well-developed flow structure is shown by the nearly parallel arrangement of the constituents, especially the laths of albite and the needles of aegirite.

The thin sections show that the albite laths range in size from less than 0.1 millimeter to several centimeters. The crystals are complexly twinned after the albite, pericline, and Carlsbad laws. The larger crystals are surrounded by or imbedded in the nepheline and microcline; the smaller laths are collected in aggregates with a trachytic texture and lie between the other constituents or are inclosed by them.

The microcline is in allotriomorphic individuals with very minute twin lamellae. It contains a little perthitically intergrown albite as well as inclusions of albite laths and needles of aegirite. It commonly has a fringe of albite on its border and is somewhat clouded with dustlike inclusions.

The nepheline is interstitial to the other constituents and commonly includes albite and aegirite. It is fairly fresh, but carries, chiefly near the borders, abundant secondary inclusions of dustlike shreds of a strongly birefracting zeolite and some irregular bodies of cancrinite and natrolite. In addition it is traversed by a complicated network of fluorite.

The aegirite is chiefly rather pale green and only slightly pleochroic, but irregular zones in the larger crystals are rather deeply colored and pleochroic. This difference in color is not associated with any considerable difference in the optical properties. It contains about 75 per cent of the acmite molecule, as indicated by the following optical properties: Ext. $X \wedge c = 5°$, $\alpha = 1.763$; $\gamma = 1.811$.

The fluorite is colorless in the sections. It fills in between the other constituents or traverses them in minute veinlets, but it is by far more prominent in the nepheline, where it forms an intricate network. It is probably of secondary origin.

TABLE III

ANALYSIS AND NORM OF NEPHELINE SYENITE*

Analysis		Norm	
SiO_2	59.13	Or	25.58
Al_2O_3	22.20	Ab	47.16
Fe_2O_3	2.04	An	1.95
FeO	.33	Ne	21.30
MgO	None		95.99
CaO	.58		
Na_2O	10.20	Il	.15
K_2O	4.35	Mg	1.39
H_2O-	.37	H	1.02
H_2O+	1.23	Wo	.35
TiO_2	.07		2.91
ZrO_2	.02		
CO_2	None	I. 6. 1. 4.	
P_2O_5	.05		
S	None		
V_2O_3	None		
MnO	.05		
BaO	None		
SrO	None		
F	.20		
	100.82		
Less O	.08		
	100.74		

* Specific Gravity = 2.639.

A chemical analysis of this nepheline syenite by George Steiger, together with the norm as calculated according to the quantitative classification, is shown in Table III.

The norm differs from the mode in the following respects: (1) The microcline of the mode contains some of the albite molecule in solid solution as well as in perthitic intergrowths. (2) Part of the albite of the norm is in solid solution in the microcline in the mode,

and a smaller part of the orthoclase of the norm is in solid solution in the albite of the mode. Part of the soda of the albite united with the iron and lime and probably the magnesia of the femic minerals of the norm to form aegirite in the mode. This aegirite of the mode required some silica, and this reduced the amount of albite and increased the amount of nepheline in the mode.

Near the crest of the ridge between Thomas and Rainy creeks the nepheline syenite of this dike is darker colored, owing to the presence of abundant needles of aegirite in bunches and streaks through the rock. The aegirite makes up about 10 per cent of the rock and occurs in bunches, streaks, and veinlets or needles and as isolated needles piercing the feldspar and nepheline. It is clearly a secondary deuteric mineral. It is associated with a little titanite, and in places coarse grains of cancrinite separate the aegirite veinlets from the feldspar and nepheline. Veinlets of fine-textured albite cut the other constituents.

Much of the rock included in the syenite probably originally contained some nepheline, now altered.

SYENITE

The large syenite body lies in the southwestern part of the Rainy Creek stock and underlies an area of a little more than 2 square miles, about half as large as that of the pyroxenite. In addition, very numerous small bodies of syenite cut the pyroxenite, and one large dike of syenite pegmatite lies near the northern border of the stock. The map shows the approximate distribution of the main syenite bodies.

Much of the syenite is so greatly altered that it is not possible to tell accurately the composition of the original rock. It varies greatly in texture and considerably in mineral composition and probably represents several separate but related intrusive masses.

A fairly uniform type of altered syenite makes up most of the mass and forms the large body that extends from the drainage basin of Thomas Creek northward across Kearney and Rainy creeks. This rock is nearly white where freshest, but is iron stained on the weathered surface. It is made up chiefly of microcline microperthite, with about 15 per cent of interstitial aggregates of coarse muscovite

plates. The microscope shows some small albite grains or laths between the microperthite tablets, also a little apatite. The microperthite is in tablets as much as 30 millimeters long and is made up of albite and microcline of about equal amounts. The muscovite is clearly secondary after some interstitial mineral, probably nepheline, and the rock originally carried from 10 to 30 per cent of this material, averaging about 15 per cent. Some of the rocks contain a little secondary rutile, and one specimen showed a little secondary biotite and 10 per cent of a pale-brown garnet with an index of refraction of 1.88, indicating andradite. The andradite is interstitial to the feldspar and penetrates the feldspar and is probably a deuteric mineral.

Another rock, less altered, is made up chiefly of perthite in crystals as much as 60 millimeters long with a little interstitial albite and sericite, probably derived from nepheline. A little dark hornblende and some fluorite, apatite, and titanite are present.

Another type of rock that makes up the dikelike body on the upper part of the ridge between Kearney and Rainy creeks is greenish gray to nearly white and carries abundant streaks and bunches that are of darker color and rich in green pyroxene and yellow titanite. The main part of the rock is made up chiefly of crystals of microperthite as much as 20 millimeters long, with about equal amounts of albite and microcline. There is more or less diopside-acmite in stout prisms, partly interstitial and partly piercing the feldspar. The larger crystals show cores of diopside. The dark patches are rich in pyroxene and titanite, both in long prisms, and some of them are made up almost entirely of these minerals. The form of the streaks and the way in which the pyroxene and titanite penetrate the feldspar strongly indicate that they are deuteric replacement deposits. The main pyroxene has the following optical properties: $\alpha = 1.720$, $\gamma = 1.752$, $X \wedge c = 21°$, which indicates a composition about midway between diopside and acmite.

The dike of coarse-grained syenite at the northern extremity of the pyroxenite body is poorly exposed, but a prospect tunnel follows it for nearly a hundred feet. The rock is giant grained and is made up mostly of perthite, but is cut by very numerous streaks and veinlets of green diopsidic aegirite. The aegirite needles penetrate the

feldspar from the veins and are clearly secondary. This diopsidic aegirite has been described by Goranson.[1]

A variety of the syenite that contains a little quartz is present west of Rainy Creek near the Ada and Joseph claims. It carries as the dark constituents a little augite, rarely biotite, and some hornblende. It is therefore intermediate between the other syenites and the granite.

GRANITE

A few dikes of nearly white granite that are only a few feet across cut the Belt rocks, and one dike, a few inches wide, cuts the syenite. The granite fabric is seriate porphyritic in a sutured fashion. Microcline with some intergrown albite and rare intergrown quartz makes up about half the rock; quartz, about a quarter; albite, a little less; diopside-acmite ($\beta = 1.736$; $X \wedge c = 19°$), about 5 per cent; and apatite, titanite, fluorite, and magnetite, a very small amount. The albite is partly intergrown with the microcline and partly in aggregates of small laths.

A small dike cutting the pyroxenite on the Ada claim is a quartz monzonite porphyry. About half of the mass consists of phenocrysts as much as 3 millimeters long, chiefly of oligoclase with some orthoclase and green hornblende. There is a little apatite, magnetite, and titanite. The groundmass is made up of quartz, orthoclase, and some albite in grains 0.1 millimeter in diameter.

HYDROTHERMAL ACTION

Hydrothermal action has been so widespread in the stock and of so unusual a character as to deserve special notice. The chief hydrothermal minerals are white mica, vermiculite, aegirite and aegirite-diopside (both in part vanadiferous), and fibrous amphiboles related to actinolite and glaucophane. Titanite, albite, zeolites, cancrinite, microcline, quartz, calcite, strontianite, celestite, chalcopyrite, pyrite, galena, and sphalerite are locally developed.

The white mica replaces a mineral, probably nepheline, in a large body of the syenite. The aegirite is developed in the nepheline syenite and particularly in the syenite pegmatite near the northern

[1] R. W. Goranson, "Aegirite from Libby, Montana," *Amer. Mineralogist*, Vol. XII (1927), pp. 37–39.

boundary of the stock. The pegmatite is traversed by numerous fractures along which are thin layers of aegirite and from which the aegirite needles penetrate some distance into the feldspar. The aegirite-diopside is chiefly associated with titanite in nodules and streaks in the syenite on the ridge between Rainy and Kearney creeks. Aegirite and aegirite-diopside (both vanadiferous) also occur in the veins that cut the pyroxenite. The albite, zeolite, and cancrinite are developed locally in the syenite and nepheline syenite.

The alterations described before all took place at very high temperature, and they are all related to the intrusion of the syenites. They are therefore mostly deuteric.

One of the most abundant of the secondary minerals is the vermiculite (jefferisite), which wholly replaces the biotite in the biotite-rich phase of the pyroxenite. It is probably of deep-seated hydrothermal origin.

THE VEINS

The veins cut the pyroxenite. The wider veins are made up mostly of quartz, and the main central parts are nearly pure quartz. Zones next the walls and only a few inches wide contain quartz but also contain in abundance vanadiferous aegirite, microcline, strontianite, celestite, pyrite, and chalcopyrite, with a little fluorite, galena, and sphalerite. The vanadiferous aegirite, which is the most conspicuous mineral of the veins, is in black needles as much as half an inch long, projecting from the wall rock or forming radiating spherulites and imbedded in the other minerals. It has been described by Larsen and Hunt.[1]

The microcline occurs in rather small amount and keeps close to the walls. The sky-blue celestite and pale-yellow strontianite are in crystals several inches in maximum diameter and are in part a little farther from the wall than the aegirite. The pyrite and chalcopyrite are mostly closely associated with the aegirite and are a little farther from the walls than the aegirite. In many narrow veinlets, less than an inch across, the narrow central part of the vein is made up of sulphides and the borders are made up chiefly of black aegirite

[1] E. S. Larsen and W. F. Hunt, "Two Vanadiferous Aegirites from Libby, Montana," *Amer. Jour. Sci.*, 4th series, Vol. XXXVI (1915), pp. 289–96.

in prisms projecting from the walls, with some microcline, celestite, and strontianite. The proportion of the central sulphide zone and the bordering aegirite zone vary rapidly from place to place, and either zone may make up nearly the whole vein.

The galena and sphalerite are mainly imbedded in the quartz, a little farther from the wall than the other sulphides.

The vanadiferous aegirite-diopside was found in a few small veins, where it is an abundant mineral in coarse spherulites and is associated with much microcline and some quartz and strontianite.[1]

The following order of deposition of the minerals of the vein can be made out fairly well: Aegirite, microcline, strontianite and celestite; pyrite and chalcopyrite; quartz with a little galena and sphalerite; and finally, quartz alone.

The pyroxenite on both sides of the veins for a distance of a few inches is greatly altered, and the boundary between the fresh and altered pyroxenite is rather sharp. In this altered zone the pyroxene is completely altered to a fibrous amphibole, related to actinolite and glaucophane, but the biotite is mostly fresh, and the apatite, garnet, and magnetite appear to be unchanged. There is some calcite, pyrite, and chalcopyrite in the altered rock. In places the biotite is partly altered to the fibrous amphibole. Locally considerable quantities of quartz and sulphides have been developed. In some places near small veinlets the pyroxenite has been less regularly altered and pyroxene crystals can be found in all stages of replacement by the amphibole. The amphibole varies considerably in composition and properties and is between glaucophane and actinolite.

It is an interesting fact that the carbonate of the vein filling is mostly strontianite (G 3.33) while that of the altered wall rock is calcite (G for the most part below 2.88). Some of the carbonate in the veins near the walls appears to have a specific gravity ranging from 2.88 to 3.33, and is a mixture of $CaCO_3$ and $SrCO_3$.

In the alteration of the pyroxene to amphibole and calcite the chief chemical changes were an oxidation of much of the ferrous iron, a large addition of soda, and some addition of potash and CO_2. The

[1] *Ibid.*, p. 295.

lime of the diopside went largely into the calcite. The sulphides required the addition of some copper and sulphur.

The workings of the Vermiculite and Asbestos Company expose several bodies of fibrous amphibole that possess dikelike forms and rather sharp and definite boundaries. They range in size from mere seams to masses as much as 14 feet wide and contain, in round figures, 90–98 per cent of amphibole, the remainder being chiefly vermiculite. Locally large faces of the adjacent pyroxenite contain from 50 to 75 per cent of the fibrous mineral.

IDENTIFICATION OF EROSION SURFACES IN SOUTH-CENTRAL NEW YORK

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ABSTRACT

There has long been a question as to whether the accordance of hill summits in south-central New York is due to peneplanation. The results of the author's study of this problem tend to show that the region was peneplained and later uplifted and dissected. This erosion surface is correlated with the so-called Schooley peneplain in central Pennsylvania. Remnants of an older erosion surface, the Kittatinny, are demonstrated to exist on the highest hills and ridges in southern New York and in central and northern Pennsylvania. Erosion surfaces, younger than the Schooley, representing partial cycles of erosion are recognized and traced, by means of projected profiles, along the Susquehanna River from Harrisburg northward.

INTRODUCTION

The plateau region of south-central New York is now dissected to the stage of early maturity. In part the topographic aspect of the region is due to the effects of the Pleistocene ice invasions. But the summits of the hills over the entire area are closely accordant in elevation (1,700–1,800 feet) and show considerable expanses of undissected flat-topped summit areas. However, the Devonian strata, of which the plateau is built, dip uniformly (if only slightly) to the south. In consequence of these relations physiographers have been in doubt whether the flat-topped upland surface of this section is a structural plain or an uplifted, dissected peneplain. This paper presents the results of an investigation devoted to the solution of this problem.

PROCESSES WHICH CAUSE PLANATION

It is recognized that the beveling of rock strata may be accomplished by any of the following processes: eolian erosion, glacial erosion, marine abrasion, or fluvial erosion.

No evidence of arid conditions relating to the existing topography has been discovered in the central New York plateau country. Hence, an assertion that wind action played an important part in the formation of the upland surface would be unwarranted by observation. It is equally improbable that ice erosion during the pe-

riod of Pleistocene glaciation developed these surfaces. In fact, the evidence available indicates that the effect of the ice action was to accentuate the relief and to reduce the area of level upland, rather than to develop it or extend it.

In his paper "Piedmont Terraces of the Northern Appalachians and Their Mode of Origin," Joseph Barrell[1] originally advanced the hypothesis that the terraces of the Piedmont region of the Atlantic Coast region are of marine origin. He has good evidence and convincing arguments in support of his conclusion that the lower terraces of southern New England and those similarly situated in the Middle Atlantic states were formed, or at least were completed, by the action of the sea. Miss Bascom,[2] following Barrell, reports: "The contact of the Honeybrook [800–900 feet] and the Schooley peneplains on the reading quadrangle . . . . suggest a sea cliff." Mrs. Knopf[3] suggests the possibility that "the Kittatinny and Schooley peneplains were formed by marine denudation." On the other hand, Campbell[4] seems to be of the opinion that the meandering courses of the Swatara and Condonoguinet creeks over the surface of the Harrisburg peneplain afford convincing evidence of subaerial base-leveling.

The complete lack of post-Paleozoic marine sediments on the uplands of the Pennsylvanian Appalachians is significantly negative, if not conclusive, evidence against marine abrasion being the effective factor in the development of the oldest surfaces at least.

A great length of time is required for the reduction of an extensive land mass to the peneplain stage. It does not appear probable that the land has remained stable in level over a period long enough for the complete peneplanation of so wide a territory as that comprised by the Eastern United States since Miocene and possibly not since the Cretaceous time. However, the presence of many erosion surfaces at different levels in this wide region indicates development

[1] *Bull. Geol. Soc. Amer.*, Vol. XXIV (1913), pp. 688–90.

[2] Florence Bascom, "Cycles of Erosion in the Piedmont Province of Pennsylvania," *Jour. Geol.*, Vol. XXIX, No. 6 (1921), p. 559.

[3] Elenora B. Knopf, "Correlation of Residual Erosion Surfaces in the Eastern Appalachian Highlands," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), p. 667.

[4] M. R. Campbell, "Geographic Development of Northern Pennsylvania and Southern New York," *ibid.*, Vol. XIV (1903), p. 278.

of the relief under interrupted cycles of erosion. The cycles vary in degrees of completion from local base-leveling to the widespread peneplanation indicated by what remains of the Kittatinny surface.

PURPOSES OF INVESTIGATION AND CRITERIA USED

The main objectives in the present investigation were as follows: (1) to seek evidence which should confirm or refute the verity of subaerial peneplanation in explanation of the level upland surfaces extending across the south-central New York area in recent geological time; and (2), if the upland surface of this section was found to be an uplifted peneplain, to attempt to correlate it with previously discerned and generally confirmed and accepted peneplains in Pennsylvania.

Many of the commonly applied criteria for the recognition of peneplains are of no significance in regions transgressed by continental glaciation. The Pleistocene ice invasions removed or greatly modified all unconsolidated residual material accumulated previous to their advances in the central New York areas. Erosion by the ice affected the bed-rock topography to such an extent that wind gaps, in this section, cannot be regarded as markers of an earlier erosion level. In general, previously existing north-south gaps have been deepened by ice action, and previously existing east-west gaps have in some cases been partially filled with glacial deposits. The contours of valley slopes have also been greatly modified by glacial scour.

It appears, therefore, that of the available criteria for peneplain identification, only those listed below can be applied in the central New York area: (1) beveling of the strata, (2) determination of accordance or non-accordance of summit levels of the hilltops, and (3) the relation of monadnock areas to structure and to regions of ancient divides.

PHYSIOGRAPHY AND STRUCTURE

The structural features of western New York and northern Pennsylvania are described by E. M. Kindle[1] in the Watkins Glen–Catatonk folio, as follows:

> There are two main groups of structural features, a general southward monocline and a series of low arches impressed upon it. While the primary

[1] "Description of the Watkins Glen–Catatonk District, New York," *U.S. Geol. Sur. Geologic Atlas*, folio 169 (1909).

tectonic relationship of these low arches is with the Allegheny folds, they also lie on the southern border of the great Canadian uplift which elevated the Paleozoic rocks of northern New York and Southern Canada. This northern uplift with its center in Southern Canada gives a general southerly dip to the Paleozoic rocks of New York south of Lake Ontario.

In the Watkins Glen–Catatonk area the folds are approximately parallel to the great Appalachian folds of Pennsylvania. According to Kindle, there are many places where the strata dip from 5° to 10°. Dip-readings made to check up on those given in the folio disclosed that, in general, the folio figures were too high. However, at one place on the southern limb of the Alpine anticline, the dip was found to be 12° and lesser flexures in the area showed even higher dips.

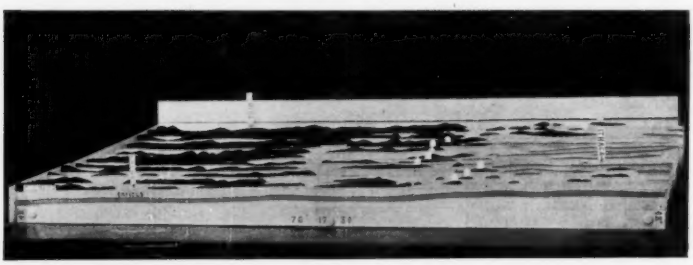

FIG. 1.—Model constructed with structure sections of the Watkins-Glen–Catatonk area, showing beveling of Upper Devonian rocks. The white markers indicate the Susquehanna-Ontario divide. Area represented, 25×35 miles.

The smaller, sharper folds are generally associated with faults and sometimes guide the courses of small streams. Probably the existence of many such minor flexures is masked by glacial drift.

BEVELING OF STRATA

Along the Pennsylvania–New York boundary line the uplands vary in elevation from 1,500 to 2,500 feet. From there the land has a general slope northward to Lake Ontario, where the elevation is 247 feet. The regional dip of the formations is south at the rate of about 40 feet per mile through central and western New York. With a northern slope of the land and a southern dip of the strata the degree of beveling of the formations is appreciable. In consequence the geologic map of northern New York west of the Adirondacks shows bands of Silurian and Devonian beds striking uniformly east-west,

with outcrops of much greater total thickness than could result from the differences in elevation. In the plateau region of southern New York, beveling of the strata is not as pronounced as it is farther north, but it is apparent in structure sections drawn with exaggerated vertical scale (Fig. 1).

A number of such structure cross-sections were made at equidistant intervals through the Watkins Glen–Catatonk area from south to north. Photographed as a group, each in its proper position, the model effect (Fig. 1) is secured. It demonstrates quite clearly the beveling of the Upper Devonian strata. Such beveling is especially marked on the Chemung, even though there is a southern

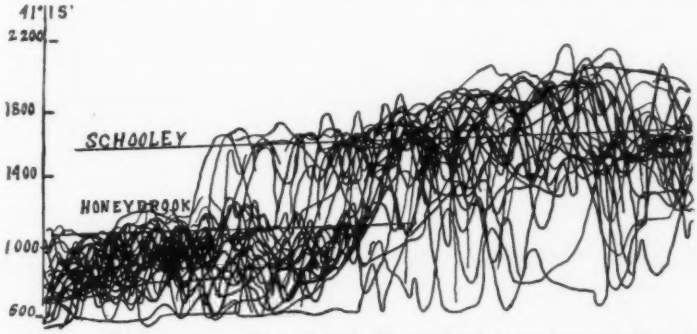

FIG. 2.—Transparency profiles, enlarged. The two levels shown here coincide with the Schooley and Honeybrook levels shown in the Trout Run section of Figure 5.

slope of the upland topography over part of the area of the outcrop of this formation.

USE OF PROJECTED PROFILES

One of the best methods for the study of erosion surfaces from topographic maps is that of projected profiles as developed and utilized by Barrell.[1] With this method the vertical scale may be exaggerated so that very slight discordances of summit levels are easily discerned.[2] In the series of projected profiles which follow, the

[1] Joseph Barrell, "The Piedmont Terraces of the Northern Appalachians," *Amer. Jour. Sci.*, 4th Ser., Vol. XLIV (1920), pp. 242–45.

[2] A modification of the projected-profile method through the use of glass plates was applied as a test to the Trout Run, Pennsylvania, quadrangle by Miss Cornelia Cornish. The topographic sheet was enlarged one and a half times, profiles were projected for each mile of the width of the map, and the sections transferred to the glass. The resulting

dotted lines in the background represent the higher elevations in the second quadrangle away from the base line. Thus, in Figure 3, the elevations of the Dryden sheet are shown by heavy lines and shading whereas the higher elevations of the Ithaca sheet are shown by dotted lines.

PROJECTED PROFILES OF THE TOWANDA-DRYDEN SECTION

In the series of profiles (Fig. 4) the meridian 78° 15′ is used as a base line, and the belt of country projected extends from Towanda, Pennsylvania, to parallel 42° 30′, a few miles north of Dryden, New York. It will be referred to as the Towanda-Dryden section.

A remarkably level surface (at 1,600–1,700 feet) is shown to extend across the greater part of the Towanda and Owego quadrangles.

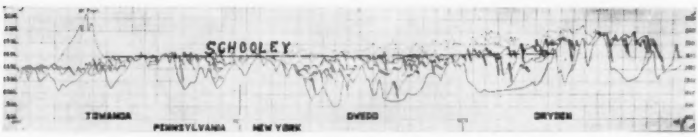

FIG. 3.—Projected profiles of the Towanda-Dryden section

The same even surface extends westward across the Wavely quadrangle and, with only a slight increase in elevation, across the area west of the Towanda quadrangle.

Unfortunately no topographic map of the country just west of Towanda is at present (1928) available. Hence there are no profiles of this territory. But the accordance of summit levels as observed in the field is remarkable in the area north and east of Mount Pisgah, situated about 14 miles west of Towanda. As the folding of the strata is more intense here[1] than it is farther north, the very marked accordance has particular value in confirming the surface to be of erosional

transparencies were then assembled in exact register and viewed by transmitted light. The result was as shown in Figure 2. It will be noted that two erosion surfaces are clearly indicated and that these correlate very closely with those further on in this paper. The transparency method provides a test by which it may be determined whether the hidden lower elevations invalidate any interpretation based on results obtained by the regular projected-profile method.

[1] On the southern limb of the Towanda anticline at Le Roy, Pennsylvania, formations dip at angles as great as 45°. Dips of 10°–15° were observed on the northern limb of this anticline.

origin. Mount Pisgah (see Fig. 3), a monadnock capped with Catskill and Pocono sandstones, rises in bold relief above this surface. Structurally, Mount Pisgah is a synclinal residual located in the Blossburg syncline. The marked accordance in elevations of the hill-

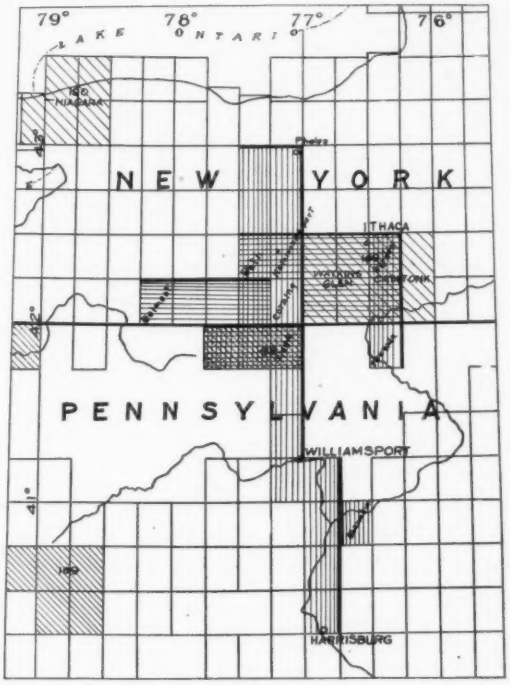

FIG. 4.—Map showing all areas from which projected profiles were made. The heavy line in each section indicates the base line.

tops in a region of steep dips, together with the occurrence of a characteristic monadnock, is quite conclusive evidence that the area was very nearly base-leveled in recent geologic time.

The greater part of the 1,600–1,700-foot surface just described is developed on the Chemung (Upper Devonian) shales and sandstones. Catskill sandstone and Chemung conglomerate are also found as capping rocks in this area. But where these formations occur,

they have apparently been beveled to a level coinciding with that developed on the stratigraphically lower Chemung shales and sandstones.

In the northern portion of the Towanda-Dryden section of profiles the 1,600–1,700-foot surface is not shown because it is shut out by the higher hills in the eastern part of the Dryden area. However, this surface is indicated in the vicinity of Ithaca at a slightly higher elevation in the (east-west) Dryden-Bath section (Fig. 7).

In the Dryden and the Ithaca quadrangles, the presence of hills which rise above the highest upland erosion surface of the region is a perplexing problem. The exceptional altitude of these hills has been attributed to the strong beds, commonly of lower Chemung, which cap them. If this is the only factor responsible for the higher elevations, then it should be found that the distinctly high points in other localities within the region also result from the comparatively great resistance of the lower Chemung.

On making a study of the geology and topography of southern New York, it is found that no such condition exists. The lower Chemung beds do not appear to be especially effective as capping layers. A more plausible reason for the greater elevations of the Ithaca-Dryden hills is that they lie in an area which forms the divide between drainage to the Susquehanna River and that to Lake Ontario. This divide region evidently was not entirely reduced at a time when territories farther south and farther north were quite completely base-leveled.

EROSION SURFACES IN PENNSYLVANIA

Two well-marked peneplains—Kittatinny and Schooley—are generally recognized in the northern Appalachian highlands. But there is no general agreement in regard to the naming or the extent of the other erosion planes which are considered to represent partially completed cycles of erosion in this region. However, a majority, probably of observers are in agreement on the appropriateness of the name and the extent of a third level, which has been called the Harrisburg surface.

Painstaking attempts at correlation of the various erosion sur-

faces in southeastern Pennsylvania have been made by Barrell,[1] Bascom,[2] and Knopf.[3] These students hold that the oldest of these surfaces, the Kittatinny, is well marked by the summits of the Blue Mountain–Kittatinny ridge, at an elevation of about 1,660 feet. This surface rises gradually toward the north. Prominent ridges on the Atlantic side of the Pennsylvania Appalachians are found to exhibit traces of many partial cycles of erosion which rise toward the north.

Blue Mountain Ridge in the Harrisburg quadrangle has an elevation of 1,300–1,350 feet, which is considered to be the elevation of the Schooley (next lower than the Kittatinny) peneplain in this section. In the Pine Grove quadrangle farther north, this ridge attains the altitude of 1,690 feet, the level of the Kittatinny. Third Mountain Ridge near Harrisburg reaches an altitude of 1,660 feet but descends to about 1,300 feet in the Pottsville quadrangle. There are many windgaps in the higher ridges which may be correlated with the summits of the lower ridges (1,300–1,350 feet). These gaps, undoubtedly, are the sites of streams which flowed slowly over the Schooley peneplain.

The very level surface in the vicinity of Harrisburg, developed over limestones and shales, at an elevation of about 560 feet is known as the Harrisburg peneplain—more accurately termed the Harrisburg base-level. This base-level can be traced in a northeastern direction as far as Delaware Water Gap, where its elevation is 700–780 feet. North of the Blue Mountain–Kittatinny ridge, evidence of the Harrisburg base-level is found at altitudes varying from 600 to 660 feet on limestones and is equally well in evidence on such weak shales as those of the Mauch Chunk formation. These base-leveled belts are of small width and lie between ridges of more resistant rock.

Barrell and Bascom each present evidence of two cycles or partial

[1] Joseph Barrell, "The Piedmont Terraces of the Northern Appalachians," *Amer. Jour. Sci.*, 4th Ser., Vol. XLIX (1920), pp. 327–62.

[2] Florence Bascom, "Cycles of Erosion in the Piedmont Province of Pennsylvania," *Jour. Geol.*, Vol. XXIX, No. 6 (1921), pp. 540–59.

[3] Elenora B. Knopf, "Correlation of Residual Erosion Surfaces in the Eastern Appalachian Highlands," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), pp. 633–68.

cycles of erosion between the Schooley and Harrisburg periods of base-leveling. The surfaces formed during these erosion cycles are termed the Honeybrook and the Sunbury. Knopf describes a third erosion surface, the Mine Ridge, just below the Schooley. The complete series of surfaces from highest to lowest accordingly is: Kittatinny, Schooley, Mine Ridge, Honeybrook, Sunbury, and Harrisburg. Of these, only the first two and the last are well authenticated and of wide development.

THE CENTRAL NEW YORK AREA

The most extended study to date of peneplanation in south-central New York is that made by M. R. Campbell.[1] In his introduction Campbell says: "The surface features of northern Pennsylvania and southern New York consist, in a broad way, of an elevated plateau so extensively dissected that only small remnants remain here and there of what appears to have been once a fairly even surface." This surface, Campbell contends, is the Harrisburg peneplain. He says that although considerably warped, this surface can be traced southward to Harrisburg, Pennsylvania, where it is well developed, and from there into Maryland and Virginia. Campbell is further of the opinion that this peneplain can be traced into western Pennsylvania and Ohio. According to his map of the "Warped Harrisburg [herein later identified with the Schooley] Peneplain," the surface of this peneplain is now dome-shaped with the summit of the dome in Potter County, Pennsylvania. According to Campbell's observations the highest points of this peneplain in Pennsylvania are represented by flat (Chemung) hilltops at a maximum altitude of 2,200 feet. The equivalent surface in the Ithaca, New York, region is apparently represented by hills capped with Chemung and Portage rocks at an altitude of from 1,700 to 1,800 feet. The Harrisburg (Schooley) peneplain is regarded by Campbell as having been completed in early Tertiary age.

The Coal Measures Plateau of the central Appalachian region is held by Campbell to be a peneplain of Cretaceous age. It is the highest well-marked level in the region. Crests along the Pennsyl-

[1] "Geographic Development of Northern Pennsylvania and Southern New York," *ibid.*, Vol. XIV (1903), p. 277.

vania–New York boundary line capped with Olean conglomerate rise to an altitude of from 2,200 to 2,500 feet. These, according to Campbell, represent remnants of the Cretaceous peneplain and are a part of the highest "Schooley or Kittatinny [really Kittatinny] peneplain of Davis."[1]

Another peneplain is described as having an altitude ranging between 300 and 500 feet and as having been developed only on rocks yielding to erosion to form river valleys such as those of the Susquehanna, Lebanon, Delaware, Lehigh, and Potomac. This erosion surface Campbell calls the Somerville peneplain, and he refers its development to late Tertiary time.

It should be realized that Campbell made his study during and prior to 1903, when much of northern Pennsylvania and southern New York was topographically unmapped. Although many quadrangle sheets in northern Pennsylvania are still lacking (1928), topographic maps are now available for the entire state of New York. With this advantage, the writer has continued the work initiated by Campbell, concentrating especially on the area of the Watkins Glen–Catatonk folio (No. 169) of the United States Geological Survey, examining and analyzing this district in detail. The reasons for such selection are that the geology of the Watkins Glen–Catatonk area has been carefully and consistently mapped and that it is centered around Ithaca, the base from which field studies were made.

CORRELATION OF EROSION SURFACES

A detailed study of the topography and structure of central New York and the northern Appalachians was made for the purpose of establishing a correlation between the erosion surfaces of the two areas. In this analysis the method of projected profiles was employed over a belt of country from Harrisburg, Pennsylvania, northward to Hammondsport, New York (Fig. 5).

THE KITTATINNY PENEPLAIN

The highest of the recognized erosion surfaces in the northern Appalachians is now very generally termed the Kittatinny peneplain. In the area studied by the writer (Fig. 5), this peneplain is

[1] W. M. Davis, "The Rivers of Northern New Jersey, with Notes on the Classification of Rivers in General," *Nat. Geog. Mag.*, Vol. II (1890), p. 86.

marked by the summit of Third Mountain in the Harrisburg quadrangle and by the slightly higher Broad Mountain summit near Millersburg. No remnant of the Kittatinny base-level appears between Broad Mountain and Nittany Mountain. The latter ridge has an altitude of 1,800 feet in the Milton quadrangle but rises to an elevation of 2,000 feet in the Williamsport quadrangle.[1]

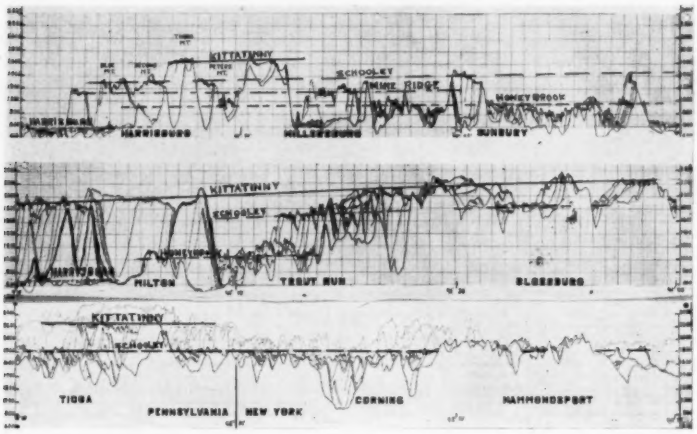

FIG. 5.—Projected profiles of 15-minute quadrangles from Harrisburg, Pennsylvania, to Hammondsport, New York.

In the northern part of the Trout Run quadrangle the Kittatinny surface ascends to an elevation of 2,200 feet (see Fig. 5). In most instances the Kittatinny peneplain, north of Williamsport as far as the state line, is preserved by ridge summits of Carboniferous conglomerates.

WARPING OF THE KITTATINNY PENEPLAIN

In the Tioga quadrangle the Kittatinny level appears at an altitude of 2,200–2,300 feet and rises to an altitude of about 2,500 feet in the western part of the Gaines quadrangle (Fig. 6). The slope of the peneplain is slightly greater in the Tioga-Gaines section (Fig. 6) than is the average slope from Tioga to Harrisburg. This increase in

[1] Both the Milton and Williamsport areas were projected on the same section. The topography of the Milton quadrangle is indicated by heavy lines, as this area is adjacent to the north-south base-line.

the peneplain slope indicates an upwarping of the Kittatinny surface in the vicinity of Gaines.

THE KITTATINNY PENEPLAIN DEVELOPMENT IN NEW YORK AND NORTHERN PENNSYLVANIA

The Kittatinny surface is preserved only in parts of the state of New York. South of Olean, at an altitude of about 2,400 feet, conglomerate-capped hills at Rock City have preserved broad remnants of the old Kittatinny surface. North of this area the summit layers of the hills are Devonian shales and sandstones, and there, only on the highest elevations, do narrow remnants of the Kittatinny pene-

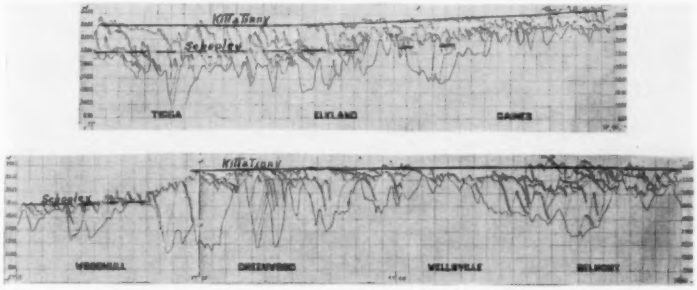

FIG. 6.—Tiogo-Gaines, Pennsylvania, and Woodhull-Belmont, New York, sections of projected profiles.

plain surface remain. In central New York, between the longitude of Hammondsport and the course of the Susquehanna River where it borders the western edge of the Catskills, very little remains of the Kittatinny peneplain.

In northern Pennsylvania between Tioga and the Catskill Mountains there are several residuals which undoubtedly mark the level of the Kittatinny peneplain. In the Blossburg syncline east of Blossburg, the Armenia Mountains and Mount Pisgah rise well above 2,200 feet. Barclay Mountain in southern Bradford County, a flat-topped ridge capped with Pottsville conglomerate, has an altitude at its highest point of 2,310 feet. Several hills southeast of Barclay Mountain also have approximately this elevation.

Summarizing, it is found that the Kittatinny peneplain appears at the altitude given for the following quadrangles in Pennsylvania:

Harrisburg, 1,650 feet; Williamsport, 1,900–2,000 feet; Tioga, 2,250–2,300 feet; Gaines, 2,400–2,450 feet. In New York the Kittatinny surface is well developed in the vicinity of Olean at an altitude of about 2,400 feet and in the western Catskills at an altitude of about 2,500 feet. In Pennsylvania this erosion surface is also indicated by the monadnocks of Mount Pisgah and Mount Barclay with elevations of 2,260 and 2,310 feet, respectively.

THE SCHOOLEY PENEPLAIN

Davis[1] originally did not differentiate between what are now termed the Kittatinny and the Schooley peneplains. The Kittatinny surface, as Davis described it, was preserved on the summits of Kittatinny Mountain and neighboring ridges at an altitude of about 1,600 feet and on the summit of Schooley Mountain at about 1,160 feet, and had a relatively steep slope.

Some years later Stose[2] concluded that there was an intermediate surface between the Kittatinny and the Harrisburg levels in the Delaware Water Gap region at an altitude of about 1,040 feet. This surface, Stose contends, is the Schooley and is indicated on Schooley Mountain at an altitude of about 1,000 feet.

Evidence provided by the presence of wind gaps at an altitude of 1,300–1,400 feet and from reduction in level of the Kittatinny Ridge near Delaware Water Gap to about the same elevation led Barrell[3] and Knopf[4] to consider such altitude as identifying and establishing the existence of a Schooley peneplain lower than the Kittatinny.[5]

[1] W. M. Davis, "The Rivers of Northern New Jersey, with Notes of the Classification of Rivers in General," *Nat. Geog. Mag.*, Vol. II (1890), pp. 81–110.

[2] George W. Stose, *A Description of the Delaware Water Gap Sheet*, U. S. Geol. Sur., 1920.

[3] Joseph Barrell, "The Piedmont Terraces of the Northern Appalachians," *Amer. Jour. Sci.*, 4th Ser., Vol. XLIX (1920), pp. 327–62, 407–28.

[4] Elenora B. Knopf, "Correlation of Residual Erosion Surfaces in the Eastern Appalachian Highlands," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), p. 647.

[5] Recently (1927) Stose has called attention to the great amount of post-Cretaceous(?) normal faulting between the Appalachian ridges and the Piedmont province. If Stose's estimate of several hundred feet of vertical displacement is correct, the erosion surfaces in the Appalachian ridges should be correlated with much lower levels in the Piedmont. However, it is not the purpose of the present investigation to correlate the erosion surfaces of these two provinces. (George W. Stose, "Possible Post-Cretaceous Faulting in the Appalachians," *ibid.*, Vol. XXXVIII (1927), pp. 493–504.)

The summit elevations of the extension of Blue Mountain into the Harrisburg quadrangle and those of Second and Peters mountains nearly all rise to a uniform altitude and undoubtedly mark the level of the Schooley peneplain. The surface of the Schooley rises gently to the northward, passing over the summits of Little and Montour mountains in the Sunbury quadrangle.

In this section the Schooley surface practically parallels the Kittatinny surface, as is demonstrated in Figure 5. The Blossburg section of profiles (Fig. 5) shows only a small extent of the Schooley, but the surface is well marked at an elevation of about 1,800 feet. The Schooley is also well developed in the Tioga, Pennsylvania, and Corning, New York, quadrangles at an elevation of about 1,800 feet. In the Hammondsport area many of the hills rise slightly above this level, but these summits are not accordant in altitude and do not indicate another higher erosion surface.

From Tioga westward the Schooley level is not well marked but may be recognized at an altitude of about 1,900 feet in the Elkland, Pennsylvania, quadrangle (Fig. 6). In the Gaines quadrangle, the Schooley level is not to be detected, except as it may occasion a terrace in valley slopes. As the Schooley surface so nearly parallels the Kittatinny, it is clear that any warping which affected the Kittatinny must also have affected the Schooley, that is, was post-Schooley in time.

The wide, level upland surface which is so plainly visible in the Corning quadrangle at an altitude of about 1,800 feet rises to a slightly higher level in the Woodhull quadrangle, which borders the Corning area on the west. The Woodhull-Belmont section of profiles (Fig. 6) shows two very distinct levels, one at an altitude of 2,300–2,400 feet and the other at an altitude of 1,800–1,900 feet. The writer deduces the lower of these levels to represent the Schooley peneplain and the higher, the Kittatinny, peneplain. The lower surface is not well marked between the Woodhull quadrangle and Olean except within the large stream valleys. This evidence does not support F. Bascom's suggestion that "in western New York it [the Schooley peneplain] appears to coalesce with the Kittatinny."[1] The

[1] Florence Bascom, "Cycles of Erosion in the Piedmont Province of Pennsylvania," *Jour. Geol.*, Vol. XXIX, No. 6 (1921), pp. 540–59.

two surfaces seem to diverge rather than coalesce in this region (Fig. 6).

The Schooley peneplain, as described in this paper, coincides approximately with Campbell's Harrisburg peneplain in northern Pennsylvania and southern New York. The great amount of warping necessary to satisfy Campbell's hypothesis of a "warped Harrisburg peneplain" becomes evident with a brief study of the projected profiles shown in Figure 5. This would mean that Kittatinny peneplanation was terminated by an upwarping in central Pennsylvania. Then, after Harrisburg (?) peneplanation, an upwarping occurred

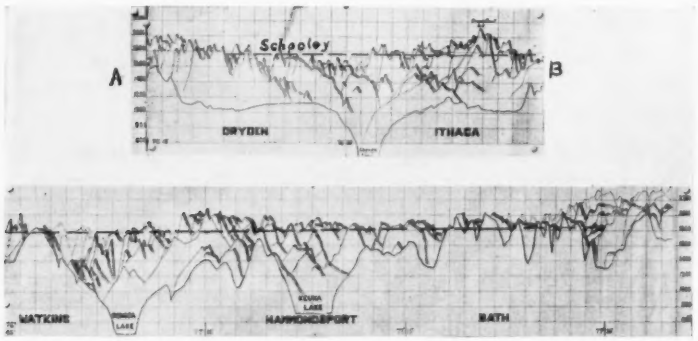

FIG. 7.—Projected profiles of the Dryden-Bath section. Vertical exaggeration approximately 26.

in northern Pennsylvania. Although a more or less continuous surface can be traced from Harrisburg northward to New York, the preponderance of evidence is against such a hypothesis.

There is a distinct level indicated in the east-west Dryden-Bath section of profiles (Fig. 7) at an altitude of 1,800–1,900 feet. This section includes much of the divide area between the Susquehanna and Ontario drainage. Thus the general level of the section is somewhat higher than the country on either side (Fig. 3). A study of the topography in southern New York, between Corning and Binghamton, reveals a remarkable accordance in altitude of the higher summits. This level varies from 1,800 feet in the western part of the Corning quadrangle to about 1,650 feet in the Owego quadrangle,

and is interpreted to be the Schooley surface. This surface was more fully described in the discussion of the Towanda-Dryden section.

Eastward from Owego the Schooley peneplain rises gently and may be traced over the higher summits, made up of Chemung and Portage sandstones and shales, to the western edge of the Catskill Mountains.

Such flat-topped hills as South Hill and Cramhorn Mountain, situated a few miles northeast of Oneonta, New York, undoubtedly mark the level of an erosion surface. These hills are about 2,000 feet in altitude. This elevation coincides with that of the level surface described by Rich[1] in the northern Catskills. Since the Schooley has a gradual ascent from central New York eastward, these high, flat areas are rather definitely indicated as remnants of the Schooley peneplain. Rich suspected that this might be the case, as is suggested by his statement (p. 145): "No attempt is here made to assign a date to the 2,000 foot peneplain, or to correlate it with others, further than to state that it apparently continues westward across southern New York"; but he did not seek data to establish this relation.

The hills on either side of Otsego Lake (at the headwaters of the Susquehanna River) rise to a uniform altitude of 1,800–1,900 feet. North of Otsego Lake the extension of the Schooley surface has been completely reduced through the erosion of the Mohawk Valley depression. The northern limit to which upland surfaces that are remnants of the Schooley peneplain are well preserved is shown in Figure 8.

The generally lower altitudes marking the regions south of Ithaca (near the New York–Pennsylvania state boundary line) are held to be due to post-Schooley warping rather than to erosion (Fig. 8). Once interfluves are reduced to sharp ridges or peaks, as they have been in the Corning quadrangle near the Chemung River (Fig. 5), the general level of the area will be lowered rapidly. Under such circumstances reduction of upland levels below the peneplain surface should be attributed to erosion subsequent to peneplanation rather than to the warping of the peneplain surface. But if, as in the region

[1] John L. Rich, "Notes on the Physiography and Glacial Geology of the Northern Catskill Mountains," *Amer. Jour. Sci.*, 4th Ser., Vol. XXXIX (1915), pp. 137–66.

south of Ithaca, the uplands present broad, undissected, tracts of flat-topped surface, it may be concluded that their altitude, where lower than that of the peneplain levels in adjacent territory, is due to warping, particularly when such lower levels can be traced through a continuous slope to the general peneplain level, as is true here.

THE MINE RIDGE EROSION SURFACE

Mrs. Knopf[1] has recently described a level surface in southeastern Pennsylvania about 200 feet lower than that of the Schooley peneplain as it appears there. This newly recognized surface is de-

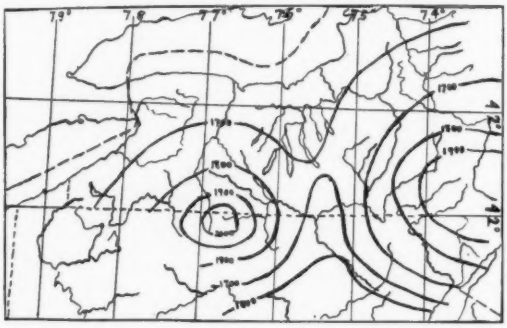

FIG. 8.—Map showing warped surface of Schooley peneplain. Contour interval, 100 feet.

scribed as being preserved on Mine Ridge at an altitude of about 800 feet. Wind gaps at elevations varying from 1,100 to 1,200 feet in Blue Mountain are considered by Knopf to mark the level of the Mine Ridge in the Blue Mountain region. Streams which now cut through Blue Mountain have composite valley slopes that give evidence of an erosion surface at the appropriate elevation.

An effort was made in the course of the present investigation to trace the Mine Ridge erosion surface from Blue Mountain, in the vicinity of Harrisburg, northward into New York. No erosion surface below the Schooley level is well developed north of Williamsport. Accordingly, the projected profiles of Figure 5 are of no serv-

[1] Elenora B. Knopf, "Correlation of Residual Erosion Surfaces in the Eastern Appalachian Highlands," *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), pp. 633–68.

ice for this purpose. The Mine Ridge surface can, however, be traced northward along the main branch of the Susquehanna.

Wind gaps at an altitude of 1,100 feet in the ridges of the Harrisburg quadrangle are considered to mark the level of the Mine Ridge surface in that locality (Fig. 5). In the Shamokin quadrangle there is a markedly level surface at an altitude of 1,150–1,200 feet (Fig. 9).

Evidence of the Mine Ridge level is present farther up the Susquehanna in the Bloomsburg and the Shickshinny quadrangles, where many flat-topped hills are accordant at altitudes of 1,200–1,250 feet. Farther east in the Pittston quadrangle, the general elevation of the hill summits on either side of the Susquehanna is about 1,200 or 1,300 feet. No topographic maps are available for the territory between the Pittston area and the state boundary line. However, north of Pittston, the composite valley slopes of the Susquehanna River and the elevations of accordant hill summits near that stream indicate an erosion surface at an altitude of 1,300–1,400 feet.

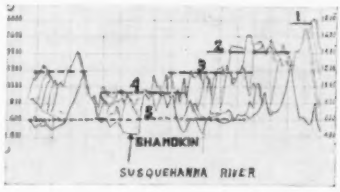

FIG. 9.—Projected profiles of the Shamokin, Pennsylvania, quadrangle, showing the various erosion surfaces. 1, Kittatinny; 2, Schooley; 3, Mine Ridge; 4, Honneybrook; 5, Harrisburg.

There are many distinct continuous rock terraces along the course of the Susquehanna River within New York State. Similar terraces at elevations from 1,400 feet down to 1,000 feet mark the valley sides of many of the streams tributary to the Susquehanna in south-central New York. However, the 1,300–1,400-foot summit level predominates in this section, and it is difficult to discriminate between lower levels. Glaciation has so much modified the minor elements of the rock topography that tracing the Mine Ridge and lower erosion surfaces from central Pennsylvania into central New York is very uncertain. However, the broad level surface east of Lake Cayuga and north of the Portage escarpment is an erosion plan which could very probably have been developed in the Mine Ridge erosion cycle, as it has the appropriate altitude for such correlation.

THE HONEYBROOK EROSION SURFACE

A level surface developed on the granite hills near Honeybrook, Pennsylvania, is described by Bascom[1] to be indicative of the Honeybrook peneplain.[2] In the Appalachian ridges of eastern Pennsylvania this Honeybrook surface is about 200 feet below the Mine Ridge. Bascom considers the summits of Godfrey Ridge and the southern foothills of Kittatinny Mountain, at an altitude of 800–900 feet, to be remnants of the Honeybrook erosion surface.

The apparent erosion surface in the Trout Run quadrangle shown in Figure 2 is at an altitude appropriate for the Honeybrook.

THE SUNBURY EROSION SURFACE

An erosion surface developed to a uniform level at the altitude of 850 feet on the steeply dipping Devonian shales and sandstones that outcrop in the vicinity of Sunbury was termed the Sunbury peneplain by Barrell.[3] However, the Sunbury cycle of erosion was evidently very brief and the tracing of the incomplete, partially-developed erosion surface that could be formed in the short time available is necessarily very difficult and uncertain.

THE HARRISBURG EROSION SURFACE

The erosion surface developed on the Martinsburg shale south of the Blue Mountain–Kittatinny Mountain ridge has been termed by Campbell[4] the "Harrisburg peneplain." This surface was more widely developed than either the Sunbury or any of the post-Harrisburg erosion surfaces. As has been noted, the Harrisburg surface was at first erroneously correlated with the Schooley level.

The Harrisburg erosion surface (or local peneplain) may be readily identified at the altitude of about 560 feet in the region of Harrisburg (Fig. 5). In the vicinity of Millersburg, a great part of the lowlands between Mahantango and Berry mountains has a level surface

[1] Florence Bascom, "Cycles of Erosion in the Piedmont Province of Pennsylvania," *Jour. Geol.*, Vol. XXIX, No. 6 (1921), pp. 540–59.

[2] The author of the present paper feels that the term "peneplain" should be reserved for the more fully completed erosion surfaces such as the Kittatinny and Schooley peneplains.

[3] Joseph Barrell, "The Piedmont Terraces of the Northern Appalachians," *Amer. Jour. Sci.*, 4th Ser., Vol. XLIX (1920), pp. 327–62.

[4] M. R. Campbell, "Geographic Development of Northern Pennsylvania and Southern New York," *Bull. Geol. Soc. Amer.*, Vol. XIV (1903), p. 284.

at an elevation of approximately 600 feet. The elevations of the lowlands bordering the Susquehanna River north of Millersburg, are, in general, slightly above 600 feet. Along the northern edge of the Milton quadrangle the low hills along the West Branch of the Susquehanna vary in altitude from 650 to 750 feet.

When the Harrisburg surface is traced along the north branch of the Susquehanna, it is found to have practically the same slope that it has along the west branch of the river. In the vicinity of Pittston, the Harrisburg erosion surface is developed on the nonresistant Carboniferous formations at an altitude of 750–800 feet.

Because topographic sheets of the territory along the Susquehanna River north of the Pittston quadrangle were not available, no attempt has been made to trace the lower surfaces farther north than Pittston.

SUMMARY

The level upland surfaces in south-central New York at elevations of 1,700–1,800 feet are held to be remnants of a well-developed erosion surface. This surface is correlated with the Schooley peneplain in the Appalachians of Pennsylvania.

Extensive remnants of an older erosion surface, the Kittatinny, are preserved in Potter, Tioga, and Bradford counties in northern Pennsylvania, in the vicinity of Rock City, near Olean, New York, and in the Catskills of New York.

The Kittatinny and Schooley surfaces are today roughly parallel and together appear to have been subject to a domed warping, with the center of this uplift in Potter County, Pennsylvania. These surfaces have a lower elevation in south-central New York than they have either farther east or farther west, a condition indicating a broad synclinal flexure as a further feature of their deformation. That a greater part of this warping of the Kittatinny and Schooley peneplain developments occurred comparatively recently, perhaps near the close of the Tertiary, is indicated by the gentle slope of the Harrisburg erosion surface in comparison with the existing slopes of the correlated remnants of the older erosion surfaces.

The Mine Ridge, the erosion surface next below that of the Schooley peneplain, is traced along the Susquehanna River from Harrisburg, Pennsylvania, into south-central New York. The level

surface at an elevation of 1,300–1,400 feet in the central New York lowlands north of Ithaca is considered to represent the Mine Ridge erosion surface.

At least three erosion levels below the Mine Ridge may be discerned in the topography of the region north from Ithaca, New York, to the shore of Lake Ontario. However, these surfaces could not be correlated definitely with similarly low surfaces demonstrated, by competent students, to exist in the Appalachians of Pennsylvania.

ACKNOWLEDGMENT

The author gratefully acknowledges indebtedness to the members of the geology department of Cornell University, Ithaca, New York—especially to Professor O. D. von Engeln—for numerous helpful suggestions during the progress of the work and the preparation of the manuscript.

A COMPOSITE STOCK AT SNOWBANK LAKE IN NORTHEASTERN MINNESOTA[1]

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ABSTRACT

This paper presents a summary of the petrology and petrography of an igneous complex of Algomian age. Comprehensively considered, it is a stock, but closer study shows that it is a stock comprising a sequence of several distinguishable phases intruded in one eruptive period.

A peculiar spotted rock which is poikilitic shonkinite (Basswood type), a quartz diorite with 13 per cent magnetite, a nordmarkite, and an aegirite-augite allanite syenite are local phases of the largest mass (syenite).

This stock is thought to be magmatically related to the Vermilion granite batholith (and probably to the Giants Range batholith), the Kekequabic granite stock, the Linden syenite stock, and the Pooh Bah malignite stock.

INTRODUCTION

Snowbank Lake, in the northern part of Lake County, Minnesota, is crossed by latitude 48° north and by longitude 91° 25′ west of Greenwich. The northern end of the lake is $2\frac{1}{2}$ miles south of the Canadian boundary. Outcrops of the composite stock occur over a more or less oval area about 5×4 miles in extent. Snowbank Lake covers a large portion of this oval, but the shores and islands furnish good exposures of the stock rocks, particularly in the south half of the area. See geologic map, Figure 1.

A review of the literature of the Snowbank Lake area brings out the fact that the area has long been considered one affording an excellent opportunity for study both of metamorphism and of magmatic differentiation. The metamorphism has been well described by N. H. Winchell, U. S. Grant, A. H. Elftmann, and others. The presence of granites, syenites, and diorites has been mentioned, but the relations of these rocks to each other have not been understood. The chief contribution of the present investigation has been the division of the whole mass into several distinguishable phases,[2] determination of the age relations, and mapping of these phases.

[1] Published by permission of the director of the Minnesota Geological Survey. This paper summarizes a thesis accepted by the faculty of the University of Minnesota in partial fulfilment for the degree of Master of Science (1926).

[2] A composite stock, as defined by Daly, "is composed of materials demonstrably intruded in two or more distinct stages of one eruptive period, the magmas of the different intrusions having different compositions."

The writer is especially indebted to Dr. F. F. Grout, of the University of Minnesota, under whose direction the work was carried

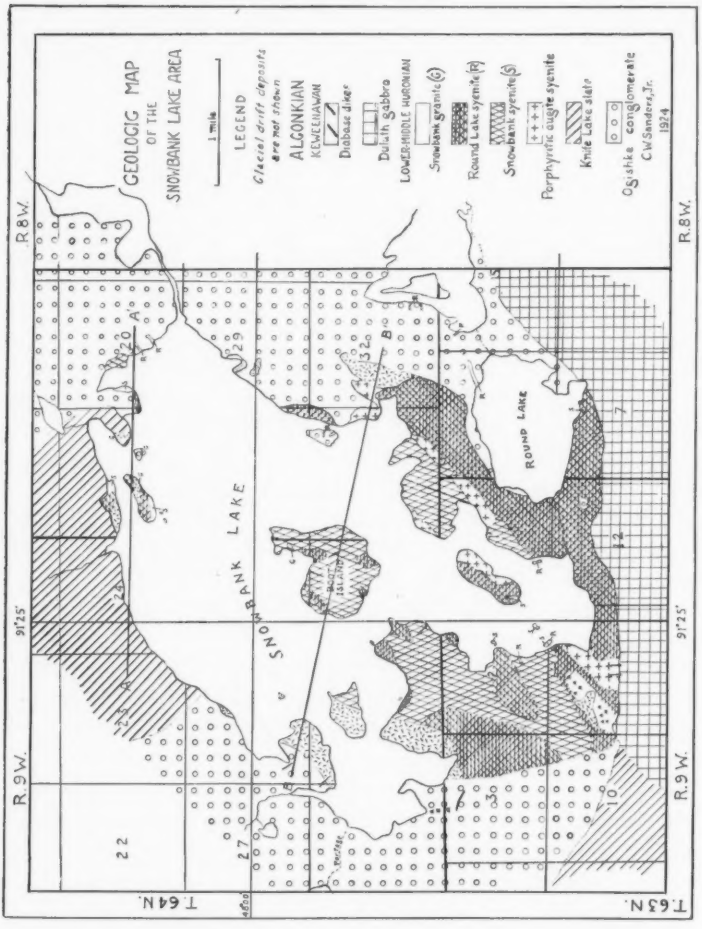

FIG. 1

out, to Dr. W. H. Emmons, director of the Minnesota Geological Survey, and to Dr. C. A. Ross, of the U.S. Geological Survey, for the loan of his thesis (unpublished) on the Snowbank syenite.

THE COMPOSITE STOCK

The composite stock is made up of (1) a stock consisting of three syenite masses of slightly differing ages, intruded by (2) another stock which is granite.

Field relations.—The stock as a whole intrudes Ogishke conglomerate and Knife Lake slate of lower-middle (?) Huronian age. The contacts are nearly vertical, except in one case. (See under "Early porphyritic augite syenite.") At the contacts the sediments have been anamorphosed to mica schists and, locally, even to gneisses. The schistosity is in general parallel to the contact with the stock, resulting in a peripheral schistosity such as is exhibited only by rocks intruded in their zone of flowage. In places the Snowbank granite seems to have soaked into the slate,[1] notably on the little peninsula in the center of the SW. $\frac{1}{4}$, Sec. 26, T. 64 N., R. 9 W. In several places injection gneiss has been formed by *lit-par-lit* injection of granite into slate.

Intrusive relations between the stock rocks, themselves, are shown in a number of exposures. This subject is treated under "Component Bodies of the Composite Stock."

In the southern part of the area the stock rocks are overlain by the north border of the Duluth gabbro laccolith, or lopolith. This gabbro has induced considerable secondary structure in the syenites and, locally, some recrystallization.

Age and correlation.—The Snowbank stock is, without much doubt, of Algomian age, intruded into lower-middle (?) Huronian sediments, and partially covered by the Duluth gabbro of Keweenawan age. Keweenawan diabase dikes cut the sediments and stock rocks. Upper Huronian (Animikean) formations are entirely absent.

Grout[2] has correlated the stock with the Vermilion granite batholith, the Kekequabic granite stock,[3] and the Linden syenite

[1] The intense metamorphism and local soaking effect led N. H. Winchell at one time to believe that the Snowbank Lake igneous rocks were formed by fusion, *in situ*, of the sediments, and that all gradations were exhibited between original sediments and igneous rocks derived therefrom.

[2] Frank F. Grout, "The Vermilion Batholith of Minnesota," *Jour. Geol.*, Vol. XXXIII (1925), pp. 469, 480–82.

[3] J. T. Stark suggests, in "The Primary Structure of the Kekequabic Granite," *Jour. Geol.*, Vol. XXXV (1927), pp. 730–31, that the Kekequabic mass is a lateral rather than a vertical intrusion, which had its source in the larger mass at Snowbank Lake, only ten miles to the southwest.

stock of Minnesota, and the Pooh Bah malignite stock of Ontario. It is probably also related to the Giants Range batholith of Minnesota.

COMPONENT BODIES OF THE COMPOSITE STOCK

The relations of the various rocks making up the stock are summarized in Table I.

TABLE I

CLASSIFICATION OF ROCK TYPES OF THE SNOWBANK COMPOSITE STOCK

I. Earliest Algomian intrusion. Perhaps a sill
   Porphyritic augite syenite
II. Stock. Snowbank syenite intruded by Round Lake syenite, with relatively short time interval between the two intrusions
   Pyroxene syenites:
   a) Diopside syenite
   b) Augite syenite
   c) Aegirite-augite syenite
      +quartz→Nordmarkite. Local acid border phase
   Biotitic hornblende syenite
      +quartz→Granite. Local acid border phase
   Special phases (segregations and basic border phases):
   a) Porphyritic syenite of Boot Island type
   b) Aegirite-augite allanite syenite
   c) Magnetite-augite-quartz diorite
   d) Augite-hornblende-biotite diorite
   e) Poikilitic syenite (Basswood type) near shonkinite
   f) Shonkinite
III. Stock. Youngest Algomian intrusion
   Hornblende granite
      Hornblende-biotite granite. Local border phase

Early porphyritic augite syenite.—The porphyritic augite syenite, which was the earliest of the Algomian intrusives, is exposed only in the southeast part of the area. Fragments of this mass are found as roof pendants in the later rocks (see Fig. 2). In Sec. 32, T. 64 N., R. 8 W., the syenite is capped by a long narrow ridge of Ogishke conglomerate, which has the appearance of a sill roof.[1]

Snowbank and Round Lake syenites.—The basin of Snowbank Lake is apparently carved for the most part in a medium-grained syenite for which the writer suggests the name "Snowbank syenite."

[1] Analogously, Stark believes that the shape of the nearby Kekequabic granite "is more that of a sheetlike mass than a deep-seated intrusion." *Op. cit.*, p. 730.

The finer syenite crops out most continuously near Round Lake, and is here called "Round Lake syenite." See geologic map, Figure 1.

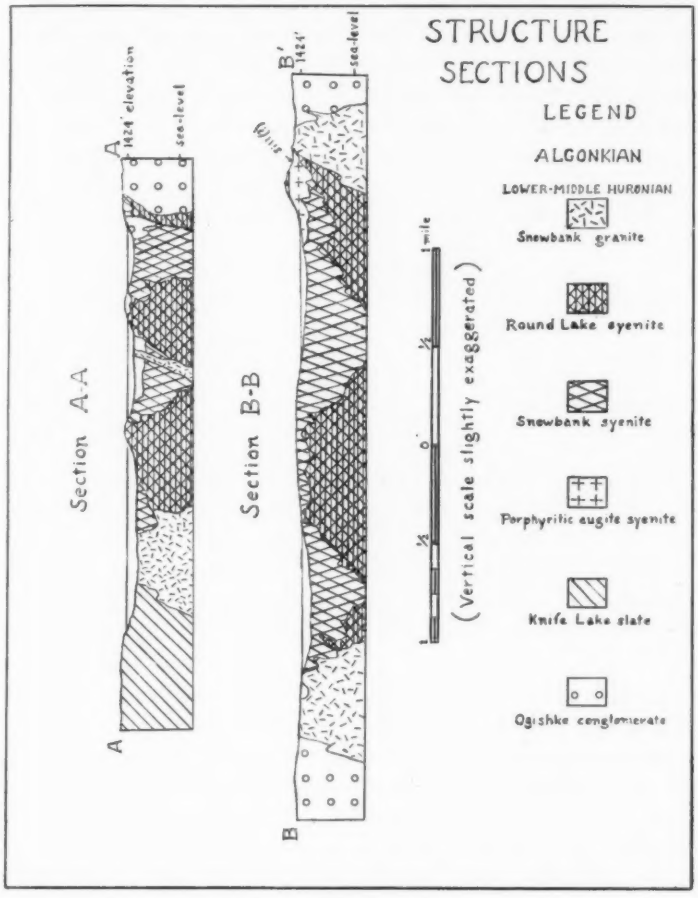

FIG. 2

On the whole, these two syenites occupy no regular zones, but occur rather sporadically, in a confusing manner.

It has been stated that, within the stock itself, intrusive relations

between syenite masses are exhibited. The relations of all three syenites are best studied along the ridge about 1,100 paces north and 400 paces west of the SE. corner of Sec. 1, T. 63 N., R. 9 W. Here the three syenites crop out close together. The porphyritic augite syenite is decidedly gneissic near the contact with the Snowbank syenite. The strike of the gneissic structure follows the curving contact. Moreover, the Snowbank syenite contains inclusions of the porphyritic syenite. The Round Lake syenite sends dikes and pegmatites into the Snowbank syenite. These relations, corroborated at other places in the area, establish the following order of intrusion: (1) Porphyritic augite syenite, (2) Snowbank syenite, (3) Round Lake syenite.

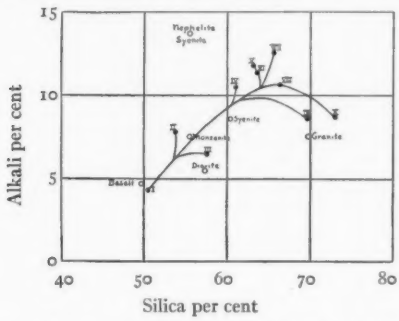

FIG. 3.—A diagram of the rock series of the Snowbank Lake composite stock. The spots show rocks whose composition has been ascertained either by chemical or micrometric analysis. The circles show the average compositions of several standard rock families for comparison. (After Grout.) Roman numerals refer to Table II.

Snowbank granite.—The main body of Snowbank granite is a separate, fairly homogeneous intrusion, younger than and cutting all the other bodies of the composite stock.

A few instructive outcrops indicating the separate intrusion of the Snowbank granite (the main body) are as follows:

1. Inclusions of syenite are found in normal granite, where both cut the Ogishke conglomerate about 200 paces south of the south shore of the little bay in NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 29, T. 64 N., R. 8 W.

2. On the east shore of the largest island in Sec. 19, T. 64 N., R. 8 W., a dike of the granite cuts a medium, red, hornblende syenite.

3. On the hill opposite the south end of the island mentioned in the preceding paragraph there is an apparent contact of the granite and a fairly coarse red, hornblende syenite, which is much fractured at the contact. Pegmatites are abundant here.

4. At a point on the shore in SW. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 26, T. 64 N., R. 9 W., a poikilitic syenite, a phase of the Snowbank syenite, is intruded by granite, and both are cut by pegmatites, probably from the granite magma.

5. The contact between granite and medium syenite can be traced for miles in the southwest and west portions of the area. Although no outcrop along this line shows granite and syenite actually contiguous, yet there are places where an outcrop of granite is within ten feet of an outcrop of syenite. The two masses retain their normal character along this line, there being no suggestion of gradation.

PETROGRAPHY OF THE MAIN MASS

The main mass of the stock is syenite and granite. The texture is generally equigranular, though porphyritic textures are not uncommon.

Feldspar is the most abundant mineral in most of the rocks. Chemical analyses of several of the rocks show that total alkalies are high, and that the soda-potash ratio is essentially constant whether the rock contains a dominance of "potash feldspar" or of "soda feldspar." In other words, what appears to be normal microcline in the thin sections must be soda-bearing microcline and the albite must be potash-bearing. These two feldspars are the most common, and they occur characteristically together as microcline-microperthite. A superfine grating structure in some of the sections suggests anorthoclase.

Ross[1] has studied the feldspars of Snowbank Lake. By microchemical and other means he proved the presence of sodium in the microcline and potassium in the albite. He states that the potassium in the albite is often important enough to cause the albite to lose its twinning striations.

In a study of the nearby Kekequabic granite, Grant[2] found that the feldspar is anorthoclase, with the approximate composition Or_5 AB_{14} An_1. Most of the Snowbank Lake rocks have soda in excess of potash, but the ratio does not seem to be as great as it is in the Kekequabic granite.

[1] C. A. Ross, unpublished thesis, University of Illinois, 1919.

[2] U. S. Grant, *Minn. State Geol. and Nat. Hist. Survey*, Vol. XXI, pp. 43–44.

The early porphyritic augite syenite.—The early porphyritic augite syenite is characterized by the abundant and consistently rounded pink and light-gray feldspar phenocrysts which average about one-half inch in length. The ground mass is fine and contains augite, hornblende, and, less abundantly, biotite. In a typical specimen, taken from the locality where the sill-like relations of the rock are suggested (see above), the mineral composition is as follows: soda-potash feldspars, 80 per cent; augite, 13 per cent; hornblende, 3 per cent; biotite, 2 per cent; accessory titanite, magnetite, and apatite. The augite has a tendency toward aegirite-augite. Soda in the molecule, probably up to 2 or 3 per cent, is suggested by the following considerations: (1) by the pleochroism, which is X = light, grayish green, Y = light, grayish green, Z = yellowish-green. Absorption: $X = Y < Z$; (2) by the extinction angle, which attains a maximum of only 38°; (3) by analogy: the augite from the granite of Kekequabic Lake[1] (in the same petrographic province) shows approximately the same pleochroism and its maximum extinction is 37°. It has 2.63 per cent Na_2O.

Hornblende and biotite have been formed apparently by the action of the late magma on the pyroxene. In some of the specimens epidote is abundant among the secondary minerals.

Chemical composition calculated from micrometric analysis of a specimen of the porphyritic augite syenite is given under V, in Table II.

The Snowbank and Round Lake syenites.—The Snowbank and Round Lake syenites may be treated together because of their petrographic similarities and field relationships. The chief megascopic difference is the finer grain and lighter color of the rock here called Round Lake syenite. Feldspars make up an average of about 65 per cent of the Snowbank syenite and about 85 per cent of the Round Lake syenite. The medium-grained syenite, with a larger proportion of femic minerals, looks gray from a little distance. Closer megascopic inspection shows that hornblende or augite makes up nearly 40 per cent of the rock, in many cases. Most outcrops show no quartz, and the feldspars are gray or pink or both.

[1] U. S. Grant, *op. cit.*

Microscopically, these syenites are equigranular to porphyritic. The most commonly occurring minerals are soda-potash feldspars,

TABLE II

CHEMICAL COMPOSITIONS OF ROCKS AT SNOWBANK LAKE
(BOTH CHEMICALLY ANALYZED AND CALCULATED)

	I	II	III	IV	V	VI	VII	VIII	†IX	X
SiO_2	50.51	53.80	56.50	61.39	63.40	63.70	65.50	65.87	69.50	72.54
Al_2O_3	12.08	17.64	.....	15.15	18.26	17.36	.....	15.86	16.86	15.03
Fe_2O_3	10.35	3.67	.....	4.18	1.55	1.38	.....	2.14	0.50	0.43
FeO	5.36	5.03	.....	2.49	1.01	0.83	.....	1.96	0.64	0.85
MgO	5.59	4.69	.....	1.87	1.24	1.49	.....	0.82	1.45	0.88
CaO	10.46	6.36	10.40	4.15	2.39	3.75	.....	2.68	1.70	1.51
Na_2O	3.59	5.31	4.84	*5.57	*6.61	5.96	6.80	5.72	4.58	4.60
K_2O	0.80	2.56	1.68	*4.92	*5.16	5.43	6.00	5.05	3.94	4.24
H_2O+	.....	.....	.....	.....	.....	.....	.....	.....	0.42	.....
H_2O-	.....	.....	.....	.....	.....	.....	.....	.....	0.20	.....
TiO_2	1.50	1.00	.....	.....	.....	.....	.....	.....	0.53	.....
Total	100.24	100.06	(73.42)	99.72	99.62	99.90	(78.30)	100.10	100.32	100.08

* Analyzed chemically by Mr. Louis Monson, of Washington University, St. Louis.
† Analyzed chemically by the writer.
All other figures calculated from measured modes (Rosiwal method).

NOTES FOR TABLE II

I. Magnetite-augite-quartz diorite from small island near SW. cor. Sec. 19, T. 64 N., R. 8 W.

II. Hornblende-augite-biotite diorite from south shore of little bay on east side of Boot Island, NE. ¼, NW. ¼, Sec. 36, T. 64 N., R. 9 W.

III. Shonkinite from sheared belt 500 paces north and 900 paces west of SE. cor. Sec. 1, T. 63 N., R. 9 W.

IV. Aegirite-augite syenite (medium) from east of peninsula whose extremity is in center of Sec. 35, T. 64 N., R. 9 W.

V. Porphyritic augite syenite from shore in NE. ¼, SE. ¼, Sec. 31, T. 64 N., R. 8 W.

VI. Augite syenite (fine) from near shore of Round Lake, SE. ¼, NE. ¼, Sec. 1, T. 63 N., R. 9 W.

VII. Aegirite-augite-allanite syenite with 90 per cent feldspar, from shore of main lake near center of SW. ¼, NW. ¼, Sec. 12, T. 63 N., R. 9 W.

VIII. Nordmarkite from near shore, southeast of bay, in SW. ¼, Sec. 32, T. 64 N., R. 8 W.

IX. Granite from south side of large island in Sec. 35, T. 64 N., R. 9 W., 15 feet from contact with syenite.

X. Granite, typical of mass along shore on west side of contact between granite and syenite, from little bay in SE. ¼, SW. ¼, Sec. 35, T. 64 N., R. 9 W.

pyroxenes, hornblende, and biotite. Quartz becomes important in an occasional acid border phase.

The pyroxene varies from diopside to augite and aegirite-augite.

Hornblende is in places more abundant than pyroxene. Biotite seldom exceeds 5 per cent of the rocks.

The accessory minerals are magnetite, titanite, apatite, zircon, pyrite, and allanite. Secondary minerals include uralite, chlorite, biotite, kaolin, sericite, paragonite, serpentine (from diopside), epidote, and iron oxides.

Typical gray medium syenite was selected for detailed measurement. The mode is as follows: soda-potash feldspars (predominantly microcline-microperthite), 62 per cent; aegirite-augite, 17 per cent; augite, 13 per cent; biotite, 3 per cent; hornblende, 2 per cent; magnetite, apatite, and titanite, 3 per cent. Hornblende is more abundant than this in many outcrops. One gray syenite, similar in field appearance to this aegirite-augite syenite, has 30 per cent hornblende. The chemical composition calculated for typical Snowbank syenite is given in Table II, No. IV.

An average of three measured modes of Round Lake syenite is given below, but hornblende is probably more abundant than this average indicates: soda-potash feldspars (predominantly albite which probably contains notable potash[1]), 83 per cent; pyroxene, 10 per cent; biotite, 3 per cent; hornblende, 2 per cent; quartz, 2 per cent.

Snowbank granite.—The Snowbank granite is a pink rock of rather fine grain, sugary texture, and high quartz content. The dark mineral is hornblende, which seldom reaches 10 per cent of the rock. A biotite-hornblende granite occurs in the southwest part of the area. This seems to be merely a local border phase of the hornblende granite, close to the main body of Snowbank syenite.

As seen in thin sections, the Snowbank granite varies but little from the following composition: quartz, 25 per cent; soda-potash feldspars, 65 per cent; hornblende, 8 per cent. The accessory and secondary minerals are essentially the same as those mentioned for the syenites. The feldspars are also similar to those in the syenites, but microperthitic intergrowths are less common in the Snowbank granite. Hornblende is strongly pleochroic in straw yellow and green. The extinction maximum is 25°. The chemical composition calculated from the measured mode of a specimen of the granite from the west half of Sec. 35, T. 64 N., R. 9 W. closely resembles the chemical

[1] See p. 141.

analysis of the granite from the large island in the same section. See Table II, Nos. IX and X. The Snowbank granite resembles, chemically, a rock from Kekequabic Lake,[1] Minnesota, and one from the Vermilion granite, southeast of Pelican Lake,[2] Minnesota.

MINOR VARIATIONS

Nordmarkite.—An earlier granite, related to the syenite stock, is in some places an augite granite and in others a hornblende granite. Biotite may be present in either case. The quartz-bearing phases of the augite syenite may be classed as nordmarkite, since quartz seldom reaches the high percentages typical of the later granite. The later granite has not been found to contain augite.

A typical light-colored nordmarkitic phase of the syenite outcrops on the east shore of the lake. In the hand specimens the rock looks like the normal fine granitoid Round Lake syenite. The texture, as seen in thin section, is decidedly porphyritic. The rock consists of quartz, 8 per cent; soda-potash feldspars, 76 per cent; hornblende, 6 per cent; aegirite-augite, 4 per cent; augite (near diopside), 2 per cent; biotide, 2 per cent; magnetite, titanite, and apatite, about 2 per cent.

Feldspar grains, partly resorbed, form phenocrysts and a large part of the fine, granular groundmass. The inner parts of the plagioclase grains have altered to kaolin and paragonite. Quartz is in anhedral grains, but a little of it is in graphic intergrowth with the feldspar. In at least one case, an augite core grades into an outer border which is aegirite-augite. The latter shows distinct pleochroism in green and greenish brown. In this case the grain seems to be cut almost parallel to the clinopinacoid, and the maximum extinctions are readily measured along the same cleavage. The augite core extinguishes at 44°, and the aegirite-augite border at 35°. Biotite and some of the magnetite seems to be secondary. A calculated analysis of typical Snowbank Lake nordmarkite is given in Table II (No. VIII).

Porphyritic syenite of Boot Island type.—Nearly every geologist who has visited the area has remarked on the striking appearance of a porphyritic rock on the east shore of Boot Island. Many of the

[1] U. S. Grant, *op. cit.*

[2] Frank F. Grout, *op. cit.*, p. 483.

feldspar phenocrysts of this rock are an inch in length, with euhedral outlines. They compose about 25 per cent of the rock. Ross found these phenocrysts to be "untwinned oligoclase-albite containing parallel lenses of potassic feldspar." He states that some of the lenses can be identified as microcline. This rock is a variation of the Snowbank syenite, and therefore later than the porphyritic augite syenite of the east shore.

Aegirite-augite-allanite syenite.—On the shore in the SW. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 12, T. 63 N., R. 9 W. is an outcrop of a syenite which appears to be composed almost entirely of long, slender feldspar laths. A specimen of this rock, taken to represent the alkalic extreme of the syenites, exhibited in thin section a notable amount of isotropic allanite (about 4 per cent) in irregular grains. Aegirite-augite, allanite, and titanite together make up about 10 per cent of the rock. The feldspars, microperthite and albite, constitute about 90 per cent.

Poikilitic and shonkinitic segregations.—A peculiar spotted rock occurs in several places in the area. A table rock on the shore of Boot Island in the NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, Sec. 36, T. 64 N., R. 9 W. is washed clean by waves and affords opportunity for tracing a gradation from spotted rock to normal Snowbank syenite within 20 feet. Other outcrops occur on the east shore of Boot Island, near the southeast border of the mass, on the west shore of the main lake, and near the southeast border of the main syenite mass between Snowbank and Round Lakes, where it forms a belt which may be a chilled border phase.

The spotted character is due to the poikilitic habit of the feldspar, each "spot" being, in reality, a single grain of feldspar inclosing many smaller grains, such as augite, magnetite, hornblende, and biotite. The size of the spot varies from $\frac{1}{8}$ inch to about $\frac{1}{2}$ in diameter. Grout, in a study of the Vermilion granite and related masses, found spotted shonkinite in connection with four different granite masses. He states,[1] "The spotted rocks are as peculiar petrographically as in field appearance. . . . . In this late poikilitic occurrence of acid feldspar, these rocks much resemble the original shonkinites of Montana, though probably the Montana rocks are not

[1] F. F. Grout, "A Peculiar Shonkinite Related to Granite," *Amer. Jour. Sci.*, Vol. IX (June, 1925), p. 476.

spotted." Some of the poikilitic rock of the Snowbank Lake is shonkinite and some is dark syenite with about 40 per cent dark minerals. This is essentially the same as the spotted rocks (Basswood type) associated with the stocks and batholiths nearby.

Dioritic phases.—Feldspar as basic as andesine is present in several small exposures (probably early phases) of the syenite stock, notably a magnetite-augite quartz diorite, located on the small island near the southwest corner of Sec. 19, T. 64 N., R. 8 W. This rock was found to contain 13 per cent magnetite. A hornblende-biotite-augite diorite occurring on the west shore of Boot Island (related to the main syenite mass) has large scales of biotite which are even megascopically poikilitic. This biotite has as index of refraction maximum (gamma) of 1.657 ± 3, indicating, according to Grout,[1] about 25 per cent FeO and 7 per cent MgO.

Other phases.—Among the local phases of the Snowbank Lake differentiation products are gneissic border phases, dike porphyries, pegmatites, and aplites, none of which has any especially noteworthy features.

COMPARISON WITH SIMILAR PROVINCES

At Mount Ascutney, Vermont, there is a series of four main stocks of different compositions, all intruded in one eruptive epoch. The order of intrusion was, according to Daly:[2] (1) diorite stock, with gabbroic and essexitic phases, (2) nordmarkite stock, (3) pulaskite stock, and (4) alkaline biotite granite stock. These rocks crop out over an area of about 5×3 miles. The succession shows a general increase in silica content from gabbro and diorite through syenite to granite. The consanguinity of the series is indicated by the consistent high alkaline content of the various differentiates.

The composite stock forming Mount Shefford, Quebec,[3] has three component igneous bodies which crop out over an area of about 7×4 miles, completely inclosed by Cambrian and Ordovician metamorphosed sediments. The order of intrusion was: (1) essexite stock, (2)

[1] Frank F. Grout, "Notes on Biotite," *Amer. Mineralogist*, Vol. IX, No. 8 (August, 1924), pp. 159, 165.

[2] R. A. Daly, "The Geology of Ascutney Mountain, Vermont," *Bull. 209, U.S. Geol. Survey*, pp. 36–37.

[3] J. A. Dresser, *Ann. Report, Geol. Survey Canada*, Vol. XIII, Part I, 1902.

pulaskite stock, (3) nordmarkite stock. In this case the igneous material does not become progressively more salic, for Dresser has shown that the last of the three intrusions, the nordmarkite stock, closely approximates an average of the compositions of the earlier stocks.

At Haystack Mountain, Montana, Emmons[1] found an intrusive series consisting of gabbros, diorites, and related rocks which he believed were differentiated below but successively intruded, each before the preceding body had cooled, thus forming a "gradational series of rocks rather than a complex of distinctly different, intersecting rocks." This might be considered intermediate between the simple and composite type of stock.

The Conical Peak stock[2] in the Crazy Mountains, Montana, is composite in nature. An Eocene quartz diorite stock is centrally intruded by an Eocene hornblende granite stock. Weed states that this granite is "apparently the aplitic phase of the diorite."

Composite batholiths are common in the North American Cordillera. The Okanagan[3] composite batholith of the Cascade Mountains, described by Daly, may be taken as typical of this class. An early granodiorite mass is cut successively by (1) nephelite syenite and maliginite, (2) later granodiorite, (3) biotite granite, (4) a closely allied but more salic granite. Daly states that "microscopic and chemical study corroborates the already compelling field evidence that these bodies are all phases of one batholithic mass."

Discussion of the petrology.—In cases of deep solidification (implying a great time interval) a later intrusion might well be roughly localized in its ascent by the contact between earlier intrusion and country rock, stoping in parts of each. This was apparently the case with the Snowbank granite stock. On the other hand, in the case of central penetration, such as that of the Crazy Mountain granite stock into the quartz diorite stock, or of those confused patches of Round Lake syenite in Snowbank syenite, the suggestion

[1] W. H. Emmons, "The Geology of the Haystack Stock, Cowles, Park County, Montana," *Jour. Geol.*, Vol. XVI (1908), pp. 193–229.

[2] W. H. Weed, "Geology of the Little Belt Mountains, Montana," *Annual report No. 20*, Part III, *U.S. Geol. Survey* (1900).

[3] R. A. Daly, "Igneous Rocks and Their Origin" (1914), pp. 115–16, 366.

is that the earlier mass had cooled only near its roof and walls, this outer portion being reintruded by the interior fluid portion of the same *magma*, which later portion is normally less femic.

THE PROCESS OF DIFFERENTIATION

The trend of differentiation is shown in Figure 3, in which the rock series is plotted with silica and total alkalies as co-ordinates, in direct percentages. In this area there is a divergence in the series. The split seems to be from syenite to alkaline syenite, on the one hand, and to granite on the other.

It is believed that the variety of rocks is due, in the main, to processes other than assimilation. The alkalinity of the province cannot be attributed to desilication due to digested limestone. There is no limestone in the section. The only subsilicic rock stoped into the invading magma was Ely greenstone, and even that is normally mediosilicic (andesite). In a few small exposures between Snowbank Lake and Round Lake, streaks of hornblendite seem to be related to altered xenoliths which may have been Ely greenstone.

The change in magma may be referred simply to gravitative differentiation in the magmatic reservoir, the reservoir which is believed to have been the source of all the materials of the composite stock. The basic border phases may approach the composition of the early magma.

A COMPARATIVE STUDY OF DIFFERENT TYPES OF THERMAL STRATIFICATION IN LAKES AND THEIR INFLUENCE ON THE FORMATION OF MARL[1]

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Geological Survey of Canada

ABSTRACT

The results of an investigation of thermal stratification in two of the Great Lakes are compared with the thermal stratification which characterizes small lakes in the Ottawa Valley. It is shown that the warm zone or surface water commonly found in the Great Lakes during the summer has several times the thickness (five times in one comparison) of the similar surface zone of a small, relatively shallow lake. While the bottom temperatures of the large, deep lake and small, shallow lake may be essentially the same, the surface or epilimnion zone in the large lake is a few degrees lower than in the small lake, elevation and latitude being about the same. With increasing elevation in a mountain region thermal zoning becomes less distinct and may disappear entirely at the end of a valley glacier.

The relatively low temperature of the epilimnion zone in the Great Lakes and in high mountain lakes prevents by producing conditions unfavorable to marl formation the development of marl beds in lakes of great size, or in small lakes above 5,000 feet in Southern Canada.

Latitude, by controlling the temperature of lakes, sets a northern limit to the formation of marl beds, which is probably not far from the northern limit of forests in North America.

Thermal stratification of the water plays, in most lakes, a great rôle in controlling the character and volume of the life in them. The warm-water blanket worn by most lakes in summer is comparable in its influence on the contained life to that of the carbon dioxide and moisture blanket of the earth which makes life possible on its surface. The zone or blanket of relatively warm water which in summer covers the surface of a great majority of lakes is the habitat of a fauna and flora materially different from that of the cold water below it. This uppermost warm zone, known as the epilimnion, develops in spring and summer, just as the ice does in the same lakes in autumn and winter. Its thickness is considerably greater in late summer than in early summer.[2] The thickness of this zone, or its failure to develop under certain conditions, and the consequent effect on lake sediments, depends on different factors, some of which will be considered here.

[1] Published with the permission of the Director, Geological Survey of Canada.

[2] E. M. Kindle, "The Rôle of Thermal Stratification," *Royal Society of Canada*. Vol. XXI (1927), Sec. 4, Fig. 2.

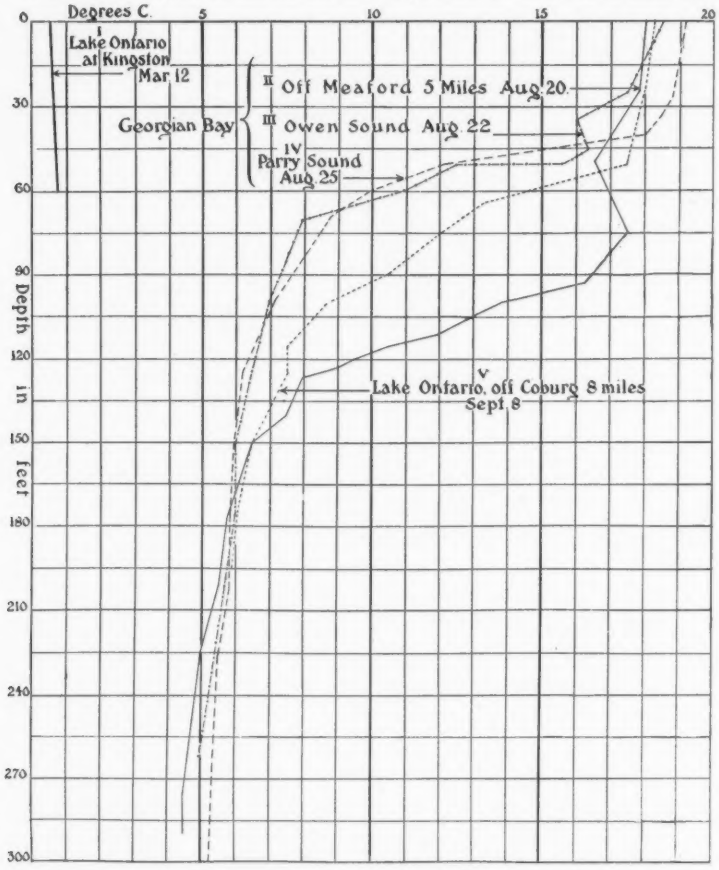
THE FACTOR OF AREA

Lakes of large size are subject to wave action of much greater intensity than small lakes. Strong currents are also active at times in lakes of great area which are unknown in small lakes.[1] Because of the greater mixing of their waters by wind and current action to which large lakes are subject, it might be expected that the thermal stratification of the largest lakes would be in some of its features notably different from what it is in small lakes.

In order to ascertain the nature and order of magnitude of the differences shown by the thermal stratification of great and small lakes, an investigation of the temperature of the waters of two of the Great Lakes was undertaken during the summer of 1927 under the writer's direction. This study was made possible by the generous financial assistance of Mr. Glen Ruby, of the Marland–Hudson Bay Oil Company, and the co-operation of Mr. K. M. Cameron, of the Department of Public Works of Canada, who arranged for some of the observations to be made from a Department of Public Works steamer. The temperature records were taken by Cecil Kindle with a self-registering Negretta and Zambra thermometer. One series of temperature readings was made in Georgian Bay, the large eastern arm of Lake Huron; another series was made in Lake Ontario. With the exception of the temperatures taken at Kingston before the "spring overturn," all of the records were made in late summer not far from the date when the maximum development of thermal stratification might be expected. The graph (Fig. 1) shows in comparable form the results of the temperature readings taken at the several stations which were occupied. Both the Georgian Bay and the Lake Ontario records show epilimnion and thermocline zones of considerable thickness. The upper stratum of warm water varies in thickness at the different stations approximately between 40 and 95 feet and the thermocline has a thickness ranging from about 30 to 75 feet. The relative magnitude of the thicknesses of the zones of water stratification in large and small lakes is graphically shown in Figure 2, where the temperatures for a Lake Ontario station are

[1] E. M. Kindle, "Bottom Deposits of Lake Ontario," *Trans. Roy. Soc. Can.*, Vol. XIX (1925), 3d Ser., pp. 30–38. "Note on Bottom Currents in Lake Ontario," *Amer. Jour. of Sci.*, Vol. XXXIX (1915), pp. 192–96.

plotted beside those of a small lake in the Ottawa Valley. Here we see the warm-water zone of the large lake extending to a depth equal to the total depth of the small lake or 50 feet, whereas the small lake



THERMAL STRATIFICATION IN GEORGIAN BAY AND LAKE ONTARIO

FIG. 1.—Thermal stratification in the Great Lakes

shows a temperature of 5° at 50 feet. In the small lake the warm water zone extends to a depth of only 10 feet, while in Lake Ontario it reaches to five times that depth. While the upper warm zone of a

very large lake will always have several times the thickness which it has in a small lake, the temperature in the latter is likely to be, as shown by the graphs, from 4° to 6° higher than it is in the large lake.

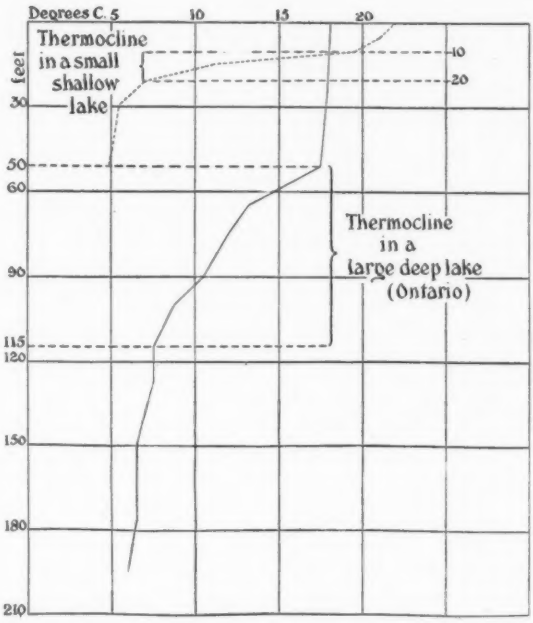


FIG. 2.—Graph showing contrast in the thickness and depth of thermocline in shallow and deep lakes. The shallow lake curve represents Fairy Lake, P.Q., July 4, and the deep water curve, Lake Ontario, September 8, 8 miles off Coburg.

This difference in temperature is due not only to the greater depth of wave action, but also to the upwelling of cold water which accompanies off-shore winds. In the Great Lakes water from the cold thermocline zone wells up only when the warm water of the surface or epilimnion zone is brushed away by off-shore winds. Off-shore winds on the beaches of the Great Lakes result in water too cold for bathing. In the small lakes the wind is not able to move sufficient surface water to produce either much upwelling on the off-shore side or undertow on the on-shore side.

INFLUENCE OF ELEVATION

Altitude is another factor which has a very important influence on thermal stratification in lakes. The lakes considered in the preceding discussion all lie less than 600 feet A.T. During the summer of 1927 the writer extended his studies of lake temperatures to lakes located at various levels between 3,250 and 6,000 A.T. in mountain valleys in the Rocky Mountains of western Alberta. It was found that the thermal zoning of the water changed from well-developed stratification in the warm lower valleys to poorly defined zoning at higher levels, and to complete absence of thermal stratification at high levels in glacier-fed lakes near the snow line. Temperatures of three lakes of comparable size and depth, but greatly contrasted elevations, are shown in the graph (Fig. 3). These clearly show the effect of increasing elevation with its lower temperature and cold-water streams in reducing thermal stratification to zero in the vicinity of a glacier. Lake Cavell has an area, depth, and drainage accession which would in midsummer, if it were located only 500 feet A.T., give it a well-defined thermocline, lying about 15 or 18 feet below the surface. Its location at 5,610 feet above sea level near a small glacier, however, entirely prevents the development of thermal stratification in it.

INFLUENCE OF AREA AND ELEVATION ON MARL FORMATION

It has been shown in an earlier paper[1] that thermal stratification is a vital factor in determining the character of the deposits which form on lake bottoms. This is notably true as regards the deposition of marl which, because of space limitations, is the only lake deposit which will be considered here. The very much greater depth to which the epilimnion and thermocline zones extend in the Great Lakes, and their lower temperatures as compared with their thickness and temperatures in small lakes, prevents in the large lakes the development anywhere of the thin zone of warm water nearly saturated with $CaCO_3$ which is essential to marl deposition. Marl is, so far as the writer has been able to discover, nowhere forming in the waters of the Great Lakes.[2] But it is often found in small lakes close-

[1] *Trans. Roy. Soc. Can.*, Vol. XXI (1927), Sec. 4, pp. 1–35.

[2] Lime-fixing algae are reported by C. H. Kindle on pebbles and rock bottom at the north end of Garden Island, opposite Kingston (verbal communication) and they

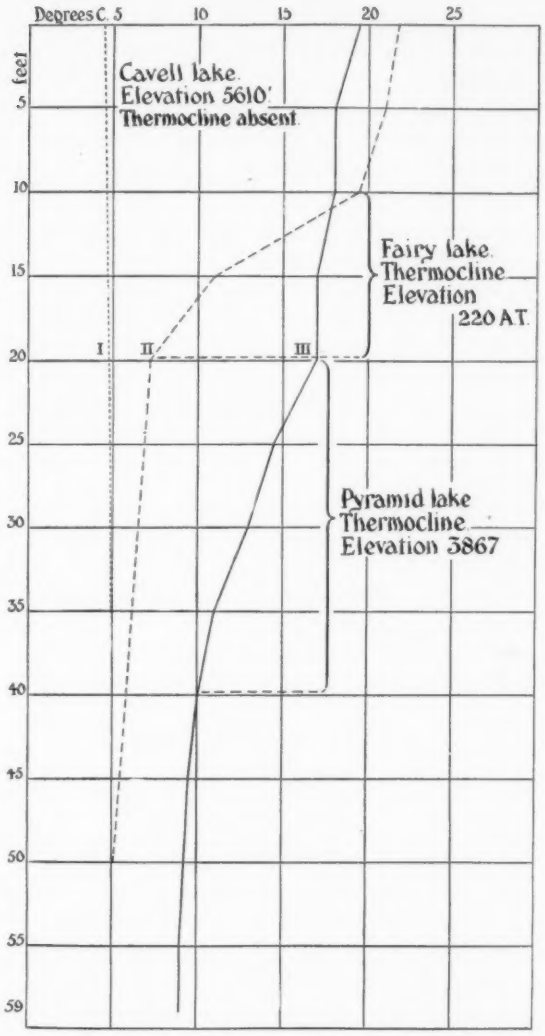


FIG. 3.—Graph of thermal stratification in lakes at contrasted elevations: (1) Cavell Lake, July 19, Jasper Park; (2) Fairy Lake, July 4, Hull, P.Q.; (3) Pyramid Lake, Jasper Park, August 16.

ly associated with the Great Lakes and separated from the large body of water only by a sandbar. West lake at Wellington, Ontario, with its marl bottom and separated only by a sandbar from Lake Ontario is an example. Its isolation permits the higher temperature and the necessary approach to saturation with $CaCO_3$ which is never attained in the open water of Lake Ontario on the same level and only a few rods distant.

The operation of the factor of elevation in modifying or preventing thermal stratification and thereby controlling marl deposition, may be seen to advantage in the numerous small lakes of Jasper Park in the Rocky Mountains of Alberta lying at all levels between 3,100 and 8,000 or 9,000 feet. In many of the small lakes north of Jasper, lying near the level of the Athabaska River at an elevation approximating 3,200 feet, marl is forming. In lake sediments which were carefully examined for marl at levels above 5,000 feet, none was found. Below 3,500 probably the majority of the small lakes in Jasper Park have marl bottoms. Above 5,000 feet there are probably no lakes with marl. Chara, Potamogeton, and other lime-separating plants are present in abundance in the lower lakes along the Athabaska. In the cold unstratified water of Lake Cavell and other high lakes examined above 5,000 feet they are absent. Lakes lying at high levels probably nowhere have thermal stratification sufficiently developed to furnish the conditions essential to the deposition of marl.

LATITUDE LIMITS OF MARL FORMATION

High latitudes, like great elevations, set a limit to marl formation. The writer has neither seen nor been able to learn of any marl deposits in North America north of 60°. No records of recent marl deposits in high latitudes of Europe have come to the writer's notice. Dr. V. Auer, of Finland, who has an intimate knowledge of the shallow lakes and peat bogs of that country, informs the writer that marl is not now forming in Finland. The apparent absence of marl deposits from the small lakes in high latitudes is doubtless due to the low mean summer temperature and consequent lack of well-devel-

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have been seen elsewhere in Lake Ontario by the writer, but beyond a thin calcareous crust no marl deposit has been formed.

oped thermal stratification. It is interesting to note how much farther north calcareous terrestrial deposits are forming in North America than marine deposits of $CaCO_3$. The region of active deposition of the materials for marine limestones lies south of 35°, while the sediments which will become fresh water limestones are accumulating as far north as about 55°.

THE MODE OF ORIGIN OF A REACTION PORPHYRY DIKE AT CORNUCOPIA, OREGON

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University of Washington

ABSTRACT

A small stocklike mass of quartz-diorite intruding feldspathic schists reacted with schist inclusions producing plagioclase phenocrysts more calcic than those indigenous to the uncontaminated magma. All stages in the development of these crystals from their initiation in the xenoliths to their occurrence as phenocrysts in the hybrid magma are clearly shown. The irruption of this magma into a fissure formed what is termed a "reaction porphyry dike."

INTRODUCTION

The association of hybrid rocks with contact breccia has previously been noted in various localities by many writers, including Clapp,[1] Högbom,[2] Harker,[3] Thomas and Bailey.[4] At Cornucopia, Oregon, the well-defined occurrence of a contact breccia indicates the probable mode of origin of what may be termed a "reaction porphyry dike."

A similar mode of origin would offer an explanation for some of the peculiar features observed in adjacent porphyry dikes.

In this region, a granodiorite batholith invaded closely folded, metamorphosed sediments and volcanics either coincident with, or immediately following, the orogeny at the close of the Jurassic or the beginning of the Cretaceous.[5] In the Miocene, after elevation and erosion to maturity, vast flows of basaltic lavas from fissure eruptions covered the older rocks. Further elevation, followed by severe

[1] C. H. Clapp, "Geology of the Igneous Rocks of Essex County, Massachusetts," *U.S. Geol. Surv. Bull. 704* (1921).

[2] A. G. Högbom, *Sueriges Geologiska Underökning om Ragundadalens Geologi*, Series C, No. 182.

[3] A. Harker, *Natural History of Igneous Rocks.*

[4] H. H. Thomas, *Tertiary and Post-tertiary Geology of Mull;* E. B. Bailey, *Memoir Geological Survey of Scotland, 1924.*

[5] Waldemar Lindgren, "The Gold Belt of the Blue Mountains of Oregon," *U.S. Geol. Survey, 22d Annual Report*, Vol. II, pp. 561–776.

mountain glaciation, affords excellent exposures of the older rocks and of the dike feeders which are especially abundant in this vicinity.

Various effects of the intrusion of the batholith are well shown both by surface outcrops and by rather extensive mine workings. Offshoots, such as porphyries, granophyres, porphyritic aplites, aplites, and quartz veins are common. The contact of the granodiorite and the older rock is irregular. In addition to numerous roof pendants several hundred feet in depth, there are large marginal apophyses or small stocklike masses, extending upward into the roof rocks.

The upper portion of one of these stocks, situated a few hundred feet in a northwesterly direction above the portals of the old Red Jacket mine tunnel, contains a swarm of angular schist xenoliths. A porphyry dike traversing the central portion of this mass exhibits in part a gradational contact with the matrix of the breccia.

THE ACIDIC DIFFERENTIATE OF THE STOCK

The stock is about 50 feet wide near the top, and appears to enlarge slightly with depth. The swarm of xenoliths occupies the central portion, leaving margins 10 feet wide which are free from inclusions. The xenoliths decrease in size from three or four inches on the outer portion of the swarm to one-half inch or less in the middle of the portion. They make up approximately 30 or 40 per cent of the breccia.

The granitic rock of this small stock is light gray in color, and finer grained than the average granodiorite of the region. In the hand specimen abundant quartz is noticeable. There is a haphazard, criss-cross arrangement of long (4 mm.) biotite crystals, which are three times as large as the blocky grains of plagioclase. In thin section this rock is seen to consist of about 29 per cent quartz, 6 per cent biotite, and 65 per cent plagioclase. The larger crystals of plagioclase are about 1.5 mm. in size, and as a rule show progressive zoning. The inner core of andesine is surrounded by an outer rim of clear untwinned albite. Many of the larger feldspars show turbid centers. A few of them have apparently been formed by the "cementing" of two smaller plagioclase individuals with clear un-

twinned albite. Many of the smaller plagioclase crystals approach oligoclase in composition. The quartz is distinctly interstitial in character. In some places it seems to have replaced the plagioclase. The biotite occurs both in long crystals and in somewhat rounded groups of smaller crystals which often contain epidote and chlorite in the central portions. One of the thin sections shows hornblende partially replaced by biotite. Another section shows what appear to

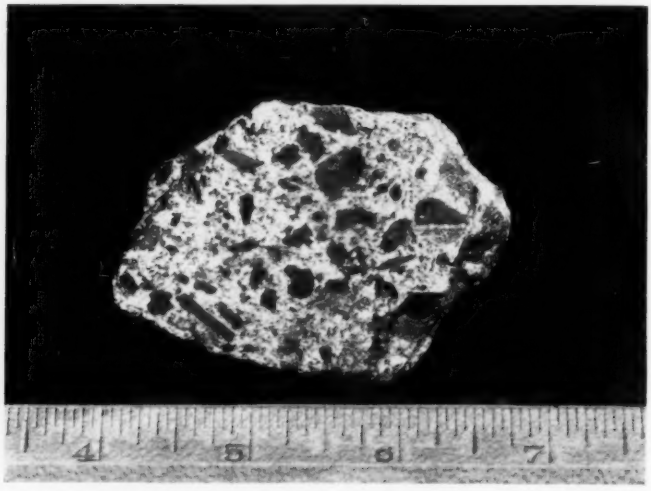

FIG. 1.—Disintegration of xenoliths

be remnants of a light-green hornblende in the central part of the groups of biotite crystals. Some biotite crystals are partially replaced by a light-green amphibole, perhaps pargasite, having a rather high extinction angle (24°). Other common mineral constituents are: sericite, magnetite, pyrite, apatite, hematite, chlorite, epidote, zoisite, limonitic and kaolinitic material.

Although the field relations indicate that this rock represents a silicic differentiate of the granodioritic magma, yet to judge from the minerals present, it appears to be more sodic as well as more silicic than the parent magma. It might be called a silicic quartz diorite.

RECRYSTALLIZATION OF INCLUSIONS AND DEVELOPMENT OF LARGER PLAGIOCLASE PHENOCRYSTS

The schist, representing much of the roof rock in the immediate vicinity, is fine grained in texture and has a slightly fissile structure. It is grayish green in color and somewhat iron stained on the surface. Under the microscope the fine-grained texture is seen to be partly mosaic in character and partly of interlocking subhedral crystals. In general, the mineral composition is about 50 per cent feldspar, chiefly plagioclase (albite) with some orthoclase, 30 per cent quartz, 20 per cent actinolite, with minor amounts of biotite, cordierite, pyrite, pyrrhotite, zoisite, limonite, magnetite, and zircon. This rock might be termed an actinolite leptynolite.

FIG. 2.—Enlarged view of fragment showing disintegration.

Most of the larger xenoliths angular in shape and two or three inches across, are very similar in composition to the main mass of the schists, differing, however, in a diminution of quartz, and in a development of hornblende. Some of the recrystallized xenoliths consist almost entirely of hornblende with subordinate biotite.

Polished sections show clearly that the breaking-up and strewing-out of the xenoliths was taking place at the time of consolidation of the magma (Figs. 1, 2, 3). Thin sections show also the disintegration of some of the xenoliths into scattered crystals of hornblende with the development of a fine-grained mosaic groundmass of quartz and feldspar.

Perhaps one of the most interesting features attending the breaking-up of the xenoliths is the development of rather large-sized individuals of plagioclase. Many examples may be seen in hand specimens or in polished sections, where plagioclase phenocrysts have developed within the xenoliths (Fig. 4), or along their borders, and may be seen inclosing hornblende crystals. Thin sections actually show some of the plagioclase crystals which were caught in the act

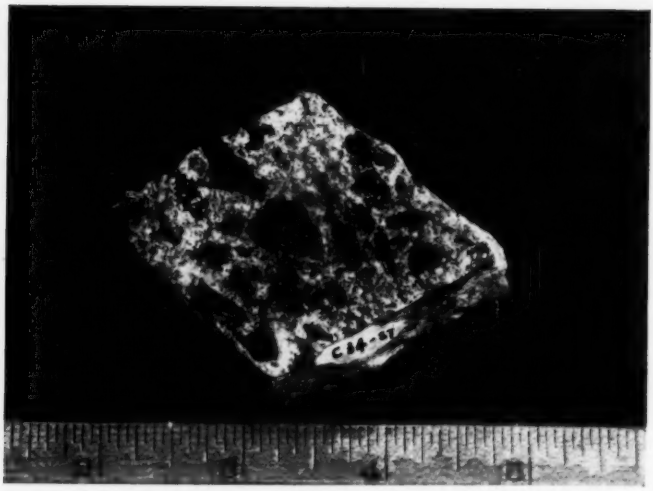

FIG. 3

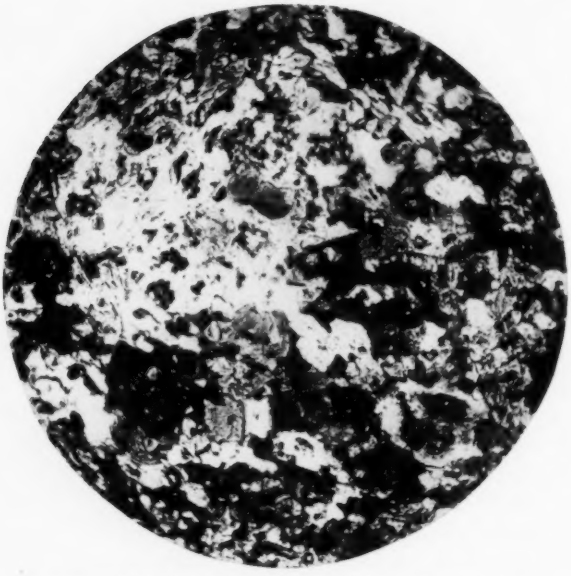

FIG. 4.—Initiation of a plagioclase crystal within a xenolith

of forming, in and near the xenoliths. In many cases one edge of these crystals is well formed, while the other has an interlocking contact with minerals of the xenoliths (Fig. 6). The digestion of the mafics (hornblende) of the xenolith and the simultaneous generation of the feldspar is thus plainly evident. These plagioclase crystals show a marked progressive zoning from a highly calcic variety in

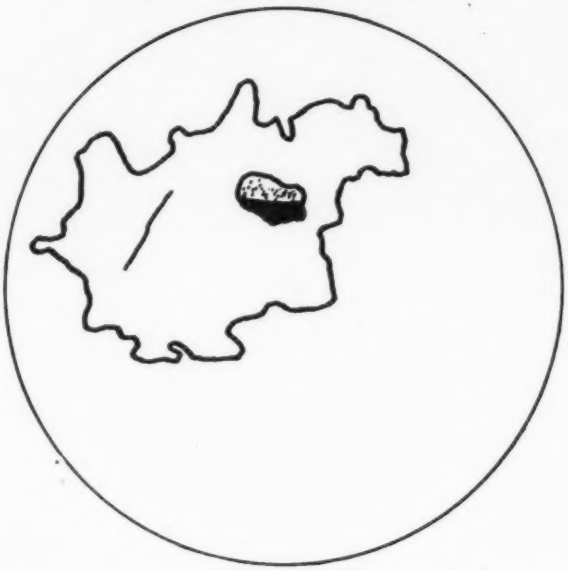

FIG. 5.—Sketch of general outline of plagioclase shown in Fig. 4. Line shows twinning plane.

contact with the mafics to a very sodic outer margin. Portions of other plagioclase crystals form integral parts of hornblende crystals, actually grading into the mafic (Fig. 7). Next to the mafic the plagioclase is very turbid, being filled with inclusions which are mainly composed of ferruginous and kaolinitic material. It seems probable that, as the hornblende was absorbed during the growth of the plagioclase, this material was left as a residual product of the reaction. Some of the detached plagioclase phenocrysts in the matrix have turbid centers which much resemble in outline what was probably the hornblende nucleus. There is even a suggestion of amphi-

bole cleavage cracks in the alteration material. Phenomena perhaps somewhat similar to this have been noted by Fenner[1] in the resorption of olivine in a basaltic magma. Just beyond the central portions of the feldspars, and extending into the clear outer albitic covering,

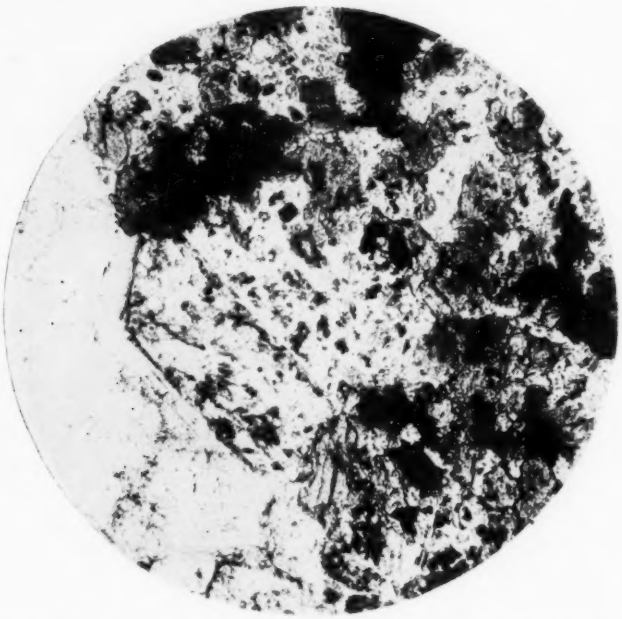

FIG. 6.—Development of plagioclase along edge of xenolith. In this photomicrograph the outer zone of clear albite is shown but faintly.

is a gradational zone turbid with minute dustlike inclusions which appear to have formed coincident with the growth of the feldspar. It is hard to believe that this ferruginous and kaolinitic material could have resulted from the processes of weathering, on account of the distribution of the alteration material, the usual presence of a complete outer rim of clear unaltered feldspar, and the unaltered occurrence in the matrix and xenoliths of other easily weathered minerals such as biotite and pyrite.

[1] C. N. Fenner, "The Crystallization of a Basaltic Magma from the Standpoint of Physical Chemistry," *Amer. Jour. Sci.*, 4th Ser., Vol. XXIX, pp. 217–36.

Some of the phenocrysts that are clear enough for determination have a central portion of labradorite which is progressively zoned to a very sodic rim of nearly pure albite. Plagioclase phenocrysts in all stages of growth or development are present, from those beginning

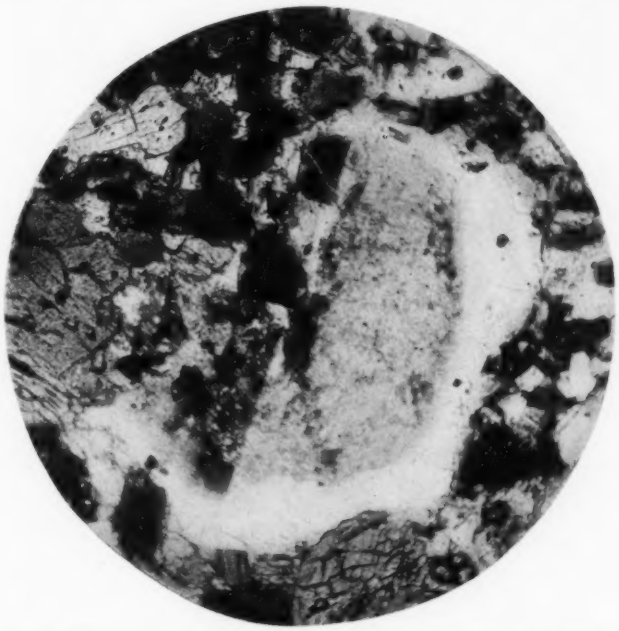

FIG. 7.—Photomicrograph of a plagioclase crystal grading into the hornblende crystals of a xenolith.

to form in or near the xenoliths to the fully formed crystals within the matrix of the breccia. Some peculiar groupings have interlocking sutured contacts. Complex twinning is common.

The facts given above seem to indicate that these feldspar crystals are the products of an interaction of a silicic melt high in volatiles with the mafic constituents of the xenoliths. Their formation appears to have taken place in several ways: (1) By growth around a mafic or group of mafic minerals dislodged from the xenoliths and distributed through the matrix. (2) By forming along the outer edges of xenoliths. (3) By growing within the xenolith. (This case

may represent a rearrangement of constituents within the fragment, initiated perhaps by the penetration of the more volatile constituents of the magma.) Thus the plagioclase crystals seem to have been

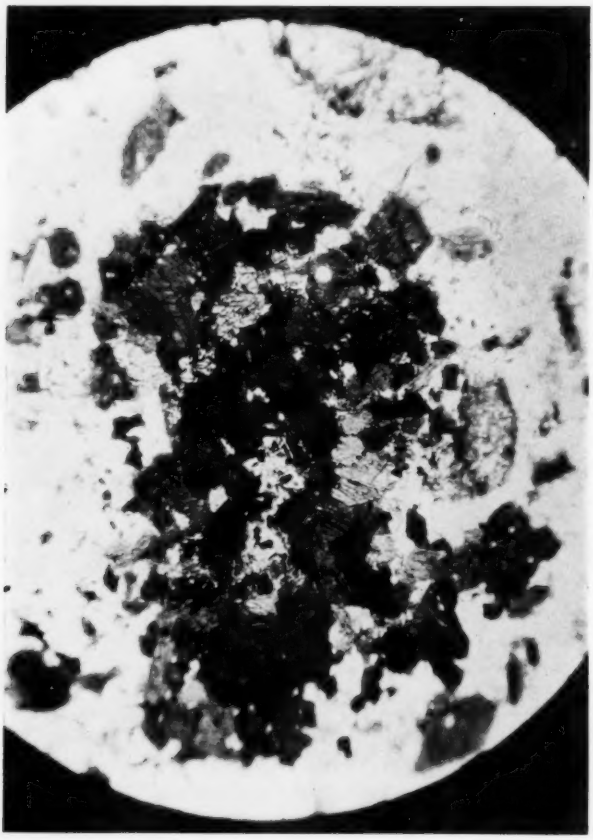

FIG. 8.—The plagioclase crystal of Fig. 4 is shown at the right-hand edge of the xenolith. Another smaller plagioclase may be seen on the opposite side.

formed during various stages of the breaking-down of the xenoliths, and not only is this mode of origin indicated, but the various steps in the process of growth are apparent.

CHANGES IN THE MATRIX OF THE BRECCIA

The effects of the xenoliths upon the quartz-diorite magma is well shown in thin sections from various parts of the breccia. In the hand specimens from near the outer portion of the swarm of larger xenoliths, the matrix looks identical with the granitic rock

FIG. 9.—Photomicrograph of plagioclase showing turbid zones

that is free from inclusions, being light gray in color and having a few elongated mafics. In the field no break can be observed between this portion and the matrix that holds the swarm of inclusions. Under the microscope, however, rather marked changes are evident. The texture is uneven and irregular, some portions being quite similar to the granitic rock, although finer grained, other portions being distinctly uneven. The plagioclase shows seriate growth ranging from 1.5 mm. down to .15 mm. in size in a peculiar-textured groundmass of sutured plagioclase and quartz. On the whole, the texture is porphyritic, while that of the rock free from xenoliths is granitic.

Hornblende instead of biotite is the predominant mafic mineral. The quartz, in part, is distinctly interstitial, and in part seems to hold small crystals of plagioclase in a pseudo-poikilitic setting. Some of the large (2 mm.) crystals of this mineral show what appear to be remnants of original biotite. On the other hand, some of the hornblende crystals seem to be replaced in part by small flakes of

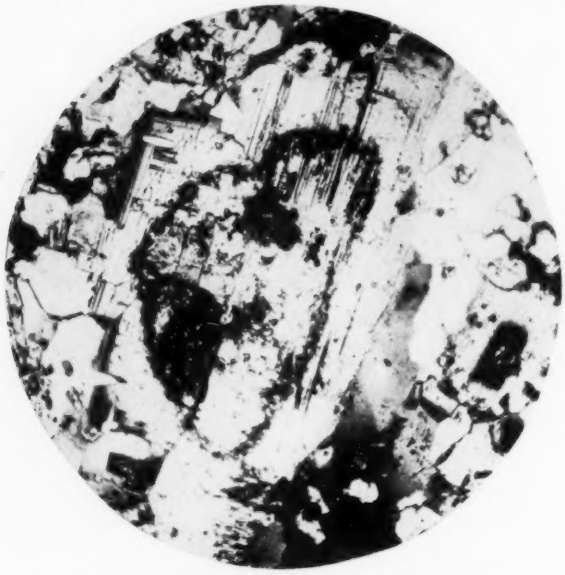

FIG. 10.—Photomicrograph of plagioclase showing turbid zones

green biotite. An approximate mineral composition is 70 per cent plagioclase (progressively zoned with more calcic centers), 15 per cent quartz, 10 per cent hornblende, and 5 per cent biotite. The minor accessories and alteration minerals are magnetite, apatite, epidote, chlorite, zoisite, sericite, and kaolin.

Toward the middle of the breccia, where the inclusions are smaller, the matrix is very different from the intrusive rock. Under the microscope the texture is seen to be a very irregular, seriate arrangement of plagioclase, from 1.5 mm. to 0.15 mm. in size, quartz largely interstitial, and the groundmass filled with minute mafics.

It is here that the development of plagioclase phenocrysts is a marked feature. Some of the plagioclase phenocrysts in the matrix have included remnants of hornblende; others, as previously stated, occur in and along the edges of recrystallized fragments. Phenocrysts of biotite and hornblende are common.

The relative abundance of the minerals in the matrix of the small-sized breccia zone is similar to that of the coarser brecciated zone except that more mafics are present, and also that the centers of the plagioclase are quite calcic, being labradorite in composition. The minor minerals are apatite, magnetite, epidote, chlorite, sericite, kaolinite, and pyrite.

Here and there scattered throughout the breccia, and especially noticeable in the central portion, are peculiar angular or subangular cavities, one or two centimeters in size. Remnants of partially decomposed xenoliths in some of the cavities suggest that the others may be due to a complete disintegration of xenoliths. This would explain their angularity. Iron staining is present in some of the cavities, but absent from others. The feldspars of the adjacent matrix do not seem to be altered. Some chloritoid was noticed. By gently scraping the inside of some of the cavities the following minerals were obtained: actinolite, limonitic material, white garnet, and feldspar. Aside from a few small specks of limonite, the rock adjacent to these cavities is rather fresh, quite hard, and compact (Figs. 11, 12).

THE REACTION PORPHYRY DIKE

In very nearly the middle of the breccia is a porphyry dike about 2 feet in width, standing nearly vertical, and having a strike of about N. 70 W. It is dark gray in color, dense porphyritic in texture, and has visible phenocrysts of feldspar, 2 mm. in size. It has a marked vertical jointing parallel to the walls of the dike. In the field the contacts are seen to be in part gradational with the matrix of the breccia, and where this is not the case, there is no apparent change in the texture of the dike along the contact, no glassy borders, nor even a finer-grained selvage.

Thin sections of this dike show an irregular porphyritic texture with phenocrysts of plagioclase in seriate arrangement, hornblende,

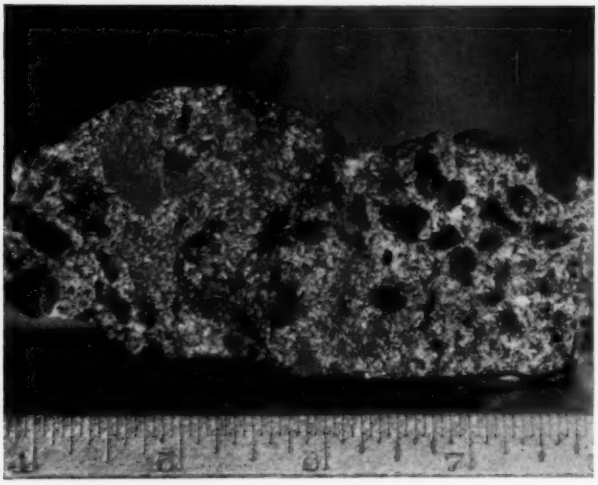

FIG. 11.—Specimen of the breccia showing cavities

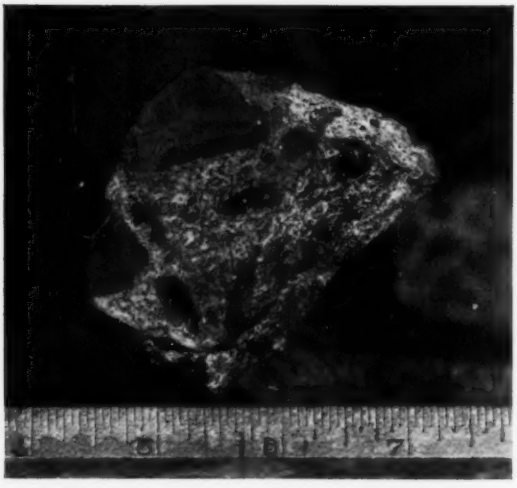

FIG. 12.—Specimen of the breccia showing cavities

biotite, and rarely quartz. The phenocrysts make up about 15 per cent of the rock. The groundmass consists chiefly of feldspar, quartz, biotite, and hornblende, with some apatite, magnetite, hematite, kaolin, chlorite, and limonite.

Most of the larger plagioclase crystals show a turbid central portion which is often quite irregular in shape. This "altered" portion is rather interesting, as in some crystals distinct remnants of hornblende are visible. The chief alteration material is a brownish (isotropic) somewhat platy limonitic material. Some kaolin and sericite are present. Although these alteration products may occur together, the central portions seem for the most part to be filled with the coarser ferruginous material, whereas the finer kaolin-sericite alteration occurs near the outer portions of the crystal next to the clear sodic rims. In some cases the alteration seems to follow, and in other cases it seems to be quite independent of previous crystallographic structure of form. Most of the feldspars are rimmed with clear albite. Oscillatory zoning is present. Many of the most altered feldspars show very irregular outlines, the clear ones rather regular outlines. The hornblende phenocrysts are of two kinds, one rather long (2 mm.), thin and green in color; the other stubby (.5 mm.) and brownish in color. One large individual of actinolite was noted. Some of the phenocrystic biotite has a peculiar flaky aggregate appearance, suggesting a possible derivation from hornblende. Quartz phenocrysts are rare, some of them are not single individuals but aggregates.

Thin sections of the contact of this dike and the matrix of the breccia are of interest. No chilling effects are present. Interlocking contacts prevail. In some parts, the demarkation between the dike and the breccia is clear, in others there is a very apparent continuation of the matrix into the dike (Figs. 13, 14).

The essential difference between the texture of the matrix and that of the dike lies in the flow structure of the latter. Where the matrix of the breccia merges with the dike there is a strong suggestion that the matrix of the breccia was actually flowing into the dike.

A comparison of the dike and the breccia, both matrix and recrystallized xenoliths, reveals striking similarities in that the kind and amounts of minerals correspond, and the same kind of feldspar

with the same type of zoning and alteration appear in both. In the dike, as might be expected, some of the albitic rims have disappeared, and the labradorite centers have started to be resorbed. With the exception of the fluxion texture in the dike, the groundmass textures are similar. The rare quartz phenocrysts in the dike are of

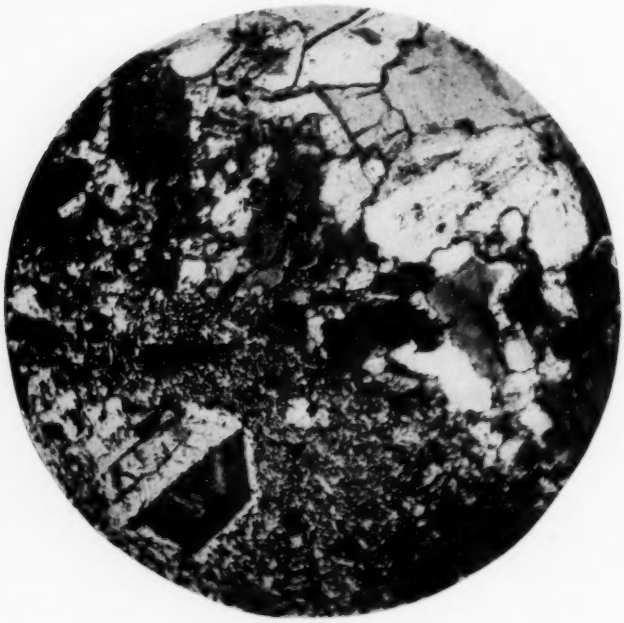

FIG. 13.—Photomicrograph of contact of porphyry dike with granitic groundmass of breccia. Phenocryst in porphyry shows turbid center and zoning.

an aggregate nature similar to some of the blebs of quartz in the breccia.

SMALL MAGMATIC RESIDUAL DIKES

The porphyry dike as well as the breccia is traversed by a small (3 or 4 inch wide), light-colored, medium-grained dike, lenticular in shape, pinching out within a few feet on either side of the porphyry dike. In thin section this rock is seen to consist of rather blocky feldspar, albite and orthoclase with some interlocking mosaic quartz

and some interstitial quartz. Albite is clearly later than some of the quartz, for it occurs in small veinlets in this mineral. All of the feldspars are altered, kaolin being the chief product. Some show rounded alteration patches with crystals of epidote in criss-cross fashion, suggesting derivation from recrystallized fragments. Some

FIG. 14.—Photomicrograph of contact of dike in part gradational with matrix of breccia.

of the feldspar seems to be replaced by quartz. There seem to be two generations of quartz, the earlier one showing an apparent strain condition, the later one a sutured mosaic texture. From the field relations and the petrographic character of this aplite dike, it seems certain that it represents the crystallization of a magmatic residual. In some portions of this breccia, aplitic dikelets, which are probably smaller magmatic residuals, are in evidence. There are also epidote veinlets.

CONCLUSIONS

The stocklike intrusion of siliceous quartz diorite magma may be taken as a starting-point. The next step was the inclusion of angular fragments of the roof rock forming a breccia. From the small area under consideration, it is obviously impossible either to develop a theory for the differentiation of the granodiorite magma into the much more acidic rock of the stock, or to state with surety the mechanism of brecciation. With regard to the latter, however, it is possible that chemical reaction played an even more important rôle than the difference in the temperature between the magma and the schist fragments. Small veinlets of quartz in the xenoliths and in the roof rock itself are indicative of the permeability of the schist by the more fluid magmatic constituents.[1]

The fragments of the roof, immersed in the acid magma of the stock, reacted with this magma, producing a type of syntectic magma which was in turn drawn off into a fissure-like mass forming what has been called a "reaction porphyry." The term "reaction" has been used to emphasize what is believed to have been the chief feature in the development of the syntectic magma.

Although the silicic quartz-diorite magma caused a rather complete recrystallization of the schist fragments, yet perhaps the clearest examples of reaction processes are shown in the development of some of the plagioclase crystals.

The changes in the silicic magma can be briefly stated. The biotite of the quartz diorite was replaced by hornblende. Then as more material reacted with the magma, there was a later development of biotite. The progressive character of these effects is evident from the fact that they are greater in the middle where the xenolithic material has been more finely divided, and less along the outer portion of coarser fragments.

The dispersion of the mineral constituents of the xenoliths in the magma may have produced a finer-textured groundmass by furnishing more centers for crystallization as well as by the actual mingling of the constituents.

Then, too, in the origin and development of the plagioclase phenocrysts, there was apparently a rather ready breakdown of the

[1] A. Lacroix, "Le granite des Pyrenées et ses phenomènes de contact," *Carte Géologique de France*, Tome 10, No. 64, 1898–99.

hornblende, the lime and alumina uniting with silica, soda, and alumina from the magma to form calcic plagioclase, some of the iron being left over as ferruginous "alteration" material, producing the turbidity of the centers; and some perhaps migrating to some other growing minerals as, for example, biotite.

The crystallization of the magma followed in general the course that would be expected according to Bowen's reaction principle:[1] the feldspars proceeded from calcic to sodic, and biotite developed later than hornblende. Some biotite seems to be replaced by hornblende. This apparent reversion of the reaction principle is probably due to contamination by the xenolithic material.

It may be supposed that the actual irruption of the dike took place when the syntectic matrix was in a more or less pasty condition, with perhaps some portions more solid than others. The fissure, whether due to orogenic forces or perhaps to the contraction incident to the consolidation of the main batholithic mass, caused an infiltration of the less consolidated material on account of the relief of pressure.

Fluxion texture in the dike forms the most striking difference between it and the matrix. Another difference is the resorption of the calcic phenocrysts in the dike. This resorption would be expected according to the reaction principle.

The gas content of the syntectic magma may have aided in its irruption. The occurrence of peculiar cavities may indicate a high volatile content. Lacroix[2] states the probable origin of certain vesicles as the result of reaction on xenoliths. Harker[3] derives similar conclusions. The presence of volatiles is also inferred from the dueteric minerals such as epidote, zoisite, and kaolinite. The occurrence of the lenticular dike traversing the porphyry dike and the matrix may be accounted for as a magmatic residual indicating further progress of the fractionation of the syntectic magma. This lenticular dike shows distinct evidence of concentration of volatiles.

Similar magmatic residuals, although smaller and more irregular,

[1] N. L. Bowen, "The Reaction Principle in Petrogenesis," *Jour. Geol.*, Vol. XXX, No. 3; "The Behavior of Inclusions in Igneous Magmas," *ibid.*, No. 6.

[2] A. Lacroix, *Les enclaves des roches volcanique.*

[3] A. Harker, "The Tertiary Igneous Rocks of Skye," *Memoirs of the Geological Survey of the United Kingdom*, 1904.

were noted in other porphyry dikes of this region, and were described in a previous paper as being due to the reaction of inclusions imposed upon the "normal" crystallization of the dike magma. The finding and study of this occurrence confirms the main thesis of irregular differentiation, and, moreover, it forms a broader factual basis for the hypothesis as to the origin of the porphyry dikes of the Cornucopia region.

In the previous paper,[1] the calcic nature and the selective alteration of the older generation of feldspars was cited as indicative that the dike magma came from a deeper, more basic phase of the granodiorite magma. This assumption seemed logical in view of the facts known at that time, but should now be discarded since the study of this reaction porphyry has given apparently definite information as to the mode and place of origin of at least one porphyry dike, and also explains the calcic phenocrysts. The similarity of this one to the other dikes of this region suggests that they had the same mode of origin.

This occurrence, as well as many others, such as the syntectic porphyry at Porcupine described by Whitman,[2] suggests that certain porphyries may be due to reaction and replacement processes, rather than to either the regular or the interrupted fractionation of a magma.

[1] G. E. Goodspeed, "Effects of Inclusions in a Small Porphyry Dike of Cornucopia, Oregon," *Jour. Geol.*, Vol. XXXV, No. 7, pp. 653–62.

[2] A. R. Whitman, "A Syntectic Porphyry at Porcupine," *Jour. Geol.*, Vol. XXXV, No. 5, pp. 404–20.

THE SOLDADO ROCK TYPE SECTION OF EOCENE

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ABSTRACT

The Soldado Rock section is a valuable stratigraphic key to basal and Upper Eocene of Northern South America. Of the six beds Nos. 2, 6, and 8 are fossiliferous. No. 2 was placed in basal Eocene (Maury, 1912) and correlated with Alabama Midway beds and Marina Farinha beds of Pernambuco. Later thought by Vaughan to be Wilcox, but basal Eocene age corroborated by discovery of same fauna in Marac quarry (Waring, 1926) where it was associated with characteristic basal Eocene species. Age of No. 2 Bed is equivalent to European Montian and Thanetian of England; Bed No. 6, foraminiferal fauna, referred by Maury and Bagg to Eocene; later by Douvillé to Oligocene, and by Tobler and Kugler to Upper Eocene. Douvillé later accepted this. Consensus of opinion of foraminiferal experts now is that Bed No. 6 is Bartonian. This permits Bed 8 to be uppermost Eocene, namely Ludian. Bed No. 8 referred by Maury to Wilcox, raised by Douvillé, Tobler, and Kugler into Oligocene, now restored to Eocene, but in uppermost member, Ludian. Bed No. 2 is the Soldado formation of Maury, 1925, and is first basal Eocene ever found in entire Antillean and Northern South American areas. Liddle's application of this name to Upper Eocene, 1928, is invalid. A new formational name (Boca de Serpiente) is now proposed for Bed No. 8 and its continuation westward in the Maracaibo basin of Venezuela.

The Soldado Rock type section and faunas described by the writer in 1912,[1] from a rocky islet in the Boca de Serpiente, Gulf of Paria, off the southwestern extremity of Trinidad Island, has become increasingly valuable as a master key to Eocene sequences in Northern South America and the islands lying to the northeast of that continent. The section was made and the fossils collected by Dr. Arthur C. Veatch, who gave me the material for study and publication. Of Dr. Veatch's eight beds, Nos. 2, 6, and 8 (ascending sequence) were fossiliferous. Because of the stratigraphic importance of the Soldado section, a revision in the light of recent investigations is urgent.

I first used the fauna of Bed No. 2 to correlate that horizon with the basal Eocene of Alabama, and with the Rio Maria Farinha beds, State of Pernambuco, Brazil, which previously had been referred to the Cretaceous. Later I was able to extend the Soldado Bed No. 2 horizon to Margarita and Toas Islands, Venezuela,[2] from specimens sent to me by Dr. Ralph Arnold.

Recently Bed No. 8 Soldado type section has been illuminating

[1] C. J. Maury, *Jour. Acad. Nat. Sci.*, Philadelphia (1912), pp. 23–112, Plates 5–13.

[2] *Amer. Jour. Sci.*, Fifth Ser., Vol. IX, No. 53 (1925), p. 412.

in the correlation of Venezuelan faunas and sections in the Maracaibo basin. For I have rediscovered far to the westward a number of the characteristic and peculiar species of this Soldado horizon.

Interesting discussions and criticisms have been written on the Soldado section and faunas, notably those by Henri Douvillé,[1] August Tobler,[2] and H. G. Kugler.[3] Very lately a long review has been given by R. A. Liddle[4] who unfortunately has misinterpreted the section very seriously. Disregarding the beds from which they came, he has grouped[5] my basal Eocene species together with those of uppermost Eocene age; transposed[6] the foraminiferal and molluscan faunas of Beds Nos. 6 and 8 respectively; and given the name Soldado formation, as new, to the Upper Eocene of Soldado Rock,[7] ignoring the fact that three years previously I had proposed the name Soldado formation[8] for Bed No. 2 Soldado, to stand, "as the type of Northern South American and of Antillean basal Eocene deposits."

Obviously Mr. Liddle's naming and use of the term Soldado formation cannot hold because of my three years' published priority. It is now necessary to give a new formational name to the Upper Eocene horizon of Soldado Rock. This will be further discussed under Bed No. 8.

Bed No. 2, Soldado formation (Maury, 1925, not of Liddle, 1928).—Bed No. 2 Soldado, which I correlated, in 1912, as basal Eocene, Monsieur Henri Douvillé, in 1915, thought Middle Eocene (Lutetian). Dr. Vaughan, in 1924, thought it equivalent to the Wilcox (Upper member of Lower Eocene). But from the fauna, I continued to think the horizon true basal Eocene. And, 1926, in the basal Eocene age of Bed No. 2 Soldado was corroborated by the discovery[9] by Waring and Harris on the nearby mainland of Trinidad Island,

[1] *Compt. Rend. Acad. Sci.*, Tome 161 (1915), pp. 97 ff.; *idem*, Tome 164, pp. 847 ff. (1917).

[2] *Eclogae Geol. Helvetiae*, Vol. XVII, p. 342.

[3] *Idem*, Vol. XVIII (1923), pp. 253–59.

[4] *Geology of Venezuela and Trinidad* (1928), pp. 223–59.

[5] *Ibid.*, pp. 223–25. [6] *Ibid.*, p. 232.

[7] *Ibid.*, p. 225 and elsewhere.

[8] *Science* (January 9, 1925), p. 43. See also *Bull. Amer. Paleont.*, No. 42 (1925), pp. 8–9.

[9] *Johns Hopkins Studies in Geology*, No. 7 (1926), pp. 99, 101.

at Marac quarry, of *Hercoglossa ulrichi* White, a very characteristic basal Eocene species; and in a quarry northeast of Point à Pierre, the very curious form, *Veatchia carolinæ* Maury,[1] from Bed No. 2 Soldado Rock, was found. The Marac and Point à Pierre quarry fossils were definitely correlated by Waring and Harris as basal Eocene. And there is no doubt that the Point à Pierre quarry horizon ties up with Bed No. 2 Soldado, because of the presence in both of the *Veatchia*, a new genus that I named in honor of Dr. Veatch, which has never yet been found except in these two localities.

Bed No. 2 is thus seen to be basal Eocene and stands stratigraphically as originally placed by me in 1912. It is equivalent to the Midway of the Southern United States, and to the European Montian, and the Thanetian of England.

This horizon, Bed No. 2 Soldado, was the first basal Eocene ever known in the Antillean or Northern South American regions. Because of its striking and interesting character, I proposed for it, in 1925, the name Soldado formation.[2] As already noted Liddle's[3] use of the term and application to Upper Eocene is invalid and untenable.

Bed No. 6 Soldado. Foraminifera abundant.—The fauna of Bed No. 6 was predominatingly foraminiferal. Dr. R. M. Bagg, to whom I sent specimens for study, thought them of Eocene age. His remarks are given on page 31 of my 1912 memoir, in the *Journal of the Philadelphia Academy*. Douvillé later thought the foraminifera indicated an Oligocene horizon. Dr. Tobler and Dr. Kugler, however, both referred the foraminifera of Bed No. 6 to the Upper Eocene. Dr. Douvillé finally also agreed to this.

The only molluscan shell in my material from Bed No. 6 was an imperfect oyster which I thought probably a left valve of *Ostrea crenulimarginata* Gabb, an Eocene species. But this shell could not be positively identified, and I left the correlation of Bed No. 6 to experts in the foraminifera.

In 1925, as noted in my memoir on the Miocene of Trinidad,[4] the age of Bed No. 6 Soldado was then thought to be Upper Eocene,

[1] *Jour. Acad. Nat. Sci.*, Philadelphia (1912), p. 90.

[2] *Science* (January 8, 1925), p. 43.

[3] *Geology of Venezuela and Trinidad* (1928), p. 225 and elsewhere.

[4] *Bull. Amer. Paleont.*, No. 42 (1925), p. 8.

about equivalent to the Jacksonian of the Southern United States. Since that time Dr. Tobler and Dr. Koch, from further study of the foraminifera, have correlated Bed No. 6 Soldado Rock as Bartonian[1] (Upper Eocene, but beneath the Ludian which is the highest member of the Upper Eocene). This decision has a very important bearing on Bed No. 8 Soldado.

Bed No. 8. The Boca de Serpiente Formation.—In Bed No. 8, as in Bed No. 2, there was a rich molluscan fauna, but the species were entirely different. The characteristically Lower Eocene forms of Bed No. 2, as *Calyptraphorus velatus* var. *compressus*, *Levifusus pagoda*, *Latirus tortilis*, *Turritella mortoni*, and *Venericardia planicosta;* the very interesting migrant from Pernambuco, *Cucullæa harttii;* and the strange new *Veatchia*, that I described as a subgenus of *Rostellaria* but which is now thought to rank as a separate genus, are all absent. In their place among the species in Bed No. 8 Soldado were two new species of *Rimella*, a *Fusoficula* like *juvenis*, and various other forms, all described in detail in my 1912 memoir. I then correlated Bed No. 8 with the Lignitic Stage of the Southern United States, which is now regarded as a synonym of the Wilcox[2] (Upper member of Lower Eocene).

But Drs. Douvillé, Tobler, and Kugler all placed Bed No. 8 Soldado in the Oligocene. For they reasoned that if Bed No. 6 with its foraminifera were Oligocene or uppermost Eocene, Bed No. 8 would necessarily be thrown into the Oligocene. I acknowledged that I had put it too low. Still the affinities of the fauna seemed to me Eocene. And in 1925, I correlated it as probably uppermost Eocene.[3]

That Bed No. 8 Soldado lies very high in the Eocene is most interestingly shown by the stratigraphic position of Venezuelan beds containing related and identical molluscan species. And since Drs. Tobler and Koch now correlate the foraminiferal bed No. 6 Soldado as Bartonian, they are willing to allow Bed No. 8 to fall into uppermost Eocene, that is Ludian.[4]

All the fossiliferous beds of the type section of Soldado Rock

[1] Communicated.

[2] Vaughan, *Bull. Geol. Soc. Amer.*, Vol. XXXV (1924), p. 721.

[3] *Bull. Amer. Paleont.*, No. 42 (1925), p. 8.

[4] Communicated.

are thus back in the Eocene, but Nos. 6 and 8 are much higher in the Eocene than originally placed.

Mr. Liddle, in his recent book on the *Geology of Venezuela and Trinidad*,[1] treats at length of an Upper Eocene, Soldado formation, which he traces from Soldado Rock into various parts of Venezuela.[2] But, as already noted, he has so confused my faunas of Beds Nos. 2, 6, and 8, that comparisons with his statements are not possible. On page 233 he states that "Maury's identifications of fossils from this island include a typical Lower and Middle Eocene fauna," and then lists indiscriminately the basal and uppermost Eocene species from Beds Nos. 2 and 8. And on page 232, Mr. Liddle says: "It is possible that the collection described by Maury was mixed, and includes forms from the Lower Eocene to and including the Lower Oligocene. This is further substantiated by the fact that only foraminifera and algal forms were found in the Oligocene, which Maury lists as Bed 8." But as clearly stated in my 1912 memoir, from which Mr. Liddle draws his information, the foraminiferal fauna was in Bed No. 6,[3] and a rich molluscan fauna was in Bed No. 8.[4]

But since, as noted under the description of Bed No. 2 in this article, the true Soldado formation (Maury, 1925)[5] is basal Eocene, Mr. Liddle's 1928 use of the term for an Upper Eocene horizon is untenable. And for the sake of clearness, I now propose for the Upper Eocene, Ludian, of Bed No. 8, described in my 1912 memoir,[6] and the continuation westward into Venezuela of this Upper Eocene horizon, the name "Boca de Serpiente formation."

SUMMARY

The present state of knowledge regarding the Soldado Rock type section may be epitomized as follows: Bed No. 8, Boca de Serpiente formation, Uppermost Eocene, equivalent to the European Ludian; Bed No. 6, foraminifera abundant, Upper Eocene, equivalent to the European Bartonian; Bed No. 2, Soldado formation (Maury, 1925, not of Liddle, 1928, which is invalid), basal Eocene, equivalent to the European Montian and the Thanetian of England.

[1] J. P. MacGowan, Publisher, Fort Worth, Texas (1928).

[2] *Geology of Venezuela and Trinidad*, p. 225, and geological map.

[3] *Jour. Acad. Nat. Sci.*, Philadelphia (1912), p. 30, also p. 31.

[4] *Op. cit.*, p. 30.

[5] *Science* (January 9, 1925), p. 43.

[6] *Jour. Acad. Nat. Sci.*, Philadelphia (1912), p. 30.

REVIEWS

Die Diamantenwüste Südwest-Afrikas. By ERICH KAISER. 2 vols. Berlin: Dietrich Reimer, 1926. Vol. I: pp. 321; figs. 59; plates 4; maps 13. Vol II: pp. 535; figs. 99; plates 52; and 32 stereo-photos.

These two splendid quarto volumes present a very comprehensive and detailed study of the geology of the coastal strip of Southwest Africa between lat. 27° S. and 27° 40′ S. Nine collaborators, in addition to Dr. Kaiser, have contributed to these volumes, thus making possible the well-rounded, detailed, and authoritative treatment of the geology of this region in its various aspects.

The older rocks comprise a basement complex of gneisses, green slates, schists, and quartzites intruded by granite, upon which rests unconformably the "Konkip" (Proterozoic?) series in which dolomite is notable; and unconformably on this is the Nama (Cambrian?) series of quartzite and dolomite. The Nama series has been folded to about the same degree as the strata in the Swiss Jura.

The younger sediments comprise several Tertiary groups, in part marine and in part terrestrial, followed by the Quaternary desert deposits, among which many large barchans are particularly striking. Considerable space has been given to the paleontology of the Tertiary beds. A large number of intrusives and extrusives of diverse types and ages make the petrographic studies an important part of the contribution.

The diamonds occur in gravel beds and fanglomerates (Pomona beds) of Tertiary age. Hypotheses for the original sources of the diamonds, and their subsequent history, are considered.

Structurally the outstanding relationship is the striking parallelism between the axial lines of the folds in the Cambrian and pre-Cambrian rocks and the present coast line, though in the southern portion of the strip the sea has cut across the folds to a slight extent, so that locally the present shore departs up to 10 or 15 degrees from the old trend lines. Though exhibiting considerable variation, by far the greatest number of the very numerous dikes strike almost exactly transverse to the folds. Three rather peculiar *graben*, with both faulting and downflexing on the sides, cut obliquely across the general structural grain of the country.

The volumes include an abundance of large-scale maps, and many of the illustrations are superb.

R. T. C.

Kohlenpetrographisches Praktikum. By E. STACH. Berlin: Gebrüder Borntraeger, 1928. Pp. 196. Figs. 64. $2.60.

This very useful book is intended to be a manual for the microscopic examination of coal, including all substances belonging to this group, from anthracite down to lignite. It deals first with the various processes of preparing thin sections for examination in transparent light and also discusses the study of coal samples by metallurgical methods. The succeeding chapters deal with the application of X-rays to the examination of coals, with the microphotography of coal preparations, with the principal constituents of coal as vitrit, durit, and fusit, with the different types of coal and their laboratory preparations, with the examination of peat and of brickettes.

It is extremely convenient to have all the different methods and facts about coal investigation under the microscope compiled in this handy volume instead of having to look for the material in hundreds of places. The book is well illustrated, and its usefulness is increased by a very complete bibliography.

The author is a geologist of the Prussian Geological Survey. Other members of the Survey who have published valuable manuals for the study of coal are W. Gothan and R. Potonié, and one of the leaders in the study of coal was H. Potonié, who died in 1913. The geologists of the Prussian Geological Survey are at liberty to publish handbooks with private publishing houses. In this way a great deal of material becomes available in the form of compilations and treatises which would otherwise be scattered through a great many bulletins and monographs, if the methods of publication to which the United States Geological Survey is limited prevailed in Berlin. Also the co-operation of private publishers with the Survey of Prussia makes the reprinting of new editions a great deal easier than is possible under the conditions now obtaining in Washington. It seems common practice with government institutions in Europe to have their publications brought out by commercial houses, whereby they are relieved of a great deal of expense, and the public can buy books in whatever fields it is interested without being handicapped by an early exhaustion of just such books and maps as are the most useful to the investigator.

A. C. NOÉ

The Optic and Microscopic Characters of Artificial Minerals. By ALEXANDER N. WINCHELL. Madison, "University of Wisconsin Studies in Science," 1927. Pp. xv+215.

In this book are given the optical properties of all of those artificial inorganic preparations whose properties have been determined. It is thus a supplement to the same author's *Optical Mineralogy, Part II.* The minerals are grouped in accordance with Dana's classification, so that the carbonates, halides, sulphides, etc., are together. The properties given are: chemical name and composition; crystal system; axial ratio; physical characters, such as crystal habit, twinning, cleavage, hardness, specific gravity, fusibility, and solubility; optic properties, including optic orientation, extinction angle, refractive indices, birefringence, optical character, optic angle, dispersion, color, and pleochroism, and, in some cases, inversions and synthesis.

Since every petrographer at times is called upon to make optical determinations on artificial preparations, a small book of this kind is very welcome. It would be invaluable to the chemist—if the chemist, as he should be, were able to use a petrographic microscope in his determinations. The larger works on the subject are all of older date and are usually inaccessible to students.

A. J.

The Downtonian and Devonian Vertebrates of Spitzbergen. Part I, *Family Cephalaspidae.* By ERIC A:SON STENSIÖ. Skrifter om Svalbard og Nordishavet, Nr. 12. Oslo: Norske Videnskaps-Akademi, 1927. 2 vols.; 391 pp.; 103 text figures; 112 pls.

A generation ago an orthodox treatment of some fragmentary Devonian cephalaspids might have consisted of a brief description of as many new species as possible. Stensiö's work, in contrast, is a comprehensive account of the structure of these primitive and curious vertebrates, with taxonomy in a subordinate rôle. For thoroughness of treatment it surpasses the majority of studies of living forms; only Allis' elaborate monographs can compare with it.

With many fossils we are forced to be content with superficialities, but in this instance the character of the material is such that the chance is given to investigate not only the skeleton but nearly every structure of the anterior part of the body. Stensiö has made the most of this opportunity. Numerous serial sections have been ground and reconstructed, and painstaking dissections made of minute structures in the hard rock (four months are said to have been spent on one small specimen the size

of a postage stamp). The matrix-filled cavities of the "skull" have enabled Stensiö to describe (in addition to the skeleton) the brain cavity, with many clues to the structure of the brain and sense organs, the complete system of cranial nerves, including an analysis of many of the functional components, and practically every important blood vessel of the head and gill region, and to gain much information regarding other systems, such as the gills and the functional pronephros.

The results of this careful description and thorough comparison shed much light upon the early history of vertebrates, as well as raising new questions. Our orthodox picture of vertebrate ancestry begins with a primitive chordate with no skeleton but a notochord (as Amphioxus), through a primitive vertebrate stage in which (as in lampreys) a cartilaginous skeleton was present but jaws absent (Cope's Agnatha), through a primitive fish stage in which the skeleton was still cartilaginous ("sharks" in a broad sense), and finally introduces bone for the first time in the higher levels of fish evolution. The ostracoderms (to which Stensiö's forms belong) have been a bar to the complete acceptance of this seemingly logical story. They comprise a group of some of our oldest Paleozoic vertebrates; they lack jaws and in some cases, at least, paired fins, and thus are to be classed among the lowest member of the phylum. Yet, unorthodoxly, they possess a dermal armor which in some cases consists of bone. Some writers have (on the basis of bone) placed them among the higher groups of fish, for which they make strange bedfellows; others (because of the absence of jaws) have grouped them with the lampreys, as Agnatha, ignoring the question of bony tissues; others have begged the question and placed them in an "appendix" to fish; Patten has seized upon them as supporting his arthropod theory of vertebrate descent.

Stensiö's previous work had already shown that certain "ostracoderms" were true fish, with bony skeletons, but in the elasmobranch stage of evolution. The present study clearly shows that the remaining three groups are really on the cyclostome level. Cephalaspis presents a combination of exceedingly primitive characters and the wildest specializations. Despite such features as the unique "electric fields," it compares point for point in many details, not merely with cyclostomes in general, but with the lampreys (Petromyzon) in particular; while another ostracoderm group seems to be closely related to the hag-fishes. The cyclostomes of today and the ancient ostracoderms are to be considered as a unit; the unossified living forms are, it seems, descended from ancestors possessing an armor, of which the mucous cartilage of the lamprey is a remnant.

It follows, Stensiö suggests, from this that an osseous skeleton must

have been an exceedingly early acquisition in vertebrates; that not only cyclostomes but elasmobranchs as well are degenerate in their skeletons; and that the higher fish, instead of creating their bony structures, have merely inherited them from a long line of ancestors. All our orthodox views are thus completely reversed, while (as Stensiö states, and as his work clearly shows) no support is given to the arachnid theories which have used the ostracoderms as a stepping-stone.

This study is an excellent illustration of the close interweaving of the interests of the vertebrate paleontologist and the comparative anatomist. To the morphologist, the paleontologist is able to offer pertinent information regarding not only osteology but often (as here) many other structural features as well. Still more important is the fact that paleontology is able to give depth to the morphological picture and present in a truer light the relationships of isolated modern forms under investigation. To the vertebrate paleontologist, no matter if his interests be in faunal, taxonomic, phylogenic, or adaptional studies, sound morphological understanding must be a basis, without which he may (and often does) wander far astray.

A. S. R.

Initial Dips Peripheral to Resurrected Hills. By JOSIAH BRIDGE and C. L. DAKE. *Missouri Bureau of Geology and Mines, 55th Bien. Rept.*, Appendix I, 1929 (Preprint, 1928). Pp. 7; pl. 1.

In the igneous area of the St. François Mountains, a hilly topography, with a maximum relief of about two thousand feet, was buried by Cambro-Ordovician seas. This topography has been largely exhumed.

Talus breccias, dolomites with igneous pebbles, and dolomites that directly overlap igneous rocks are interesting sediments.

Initial dips range up to 30°. These dips are toward the valley axes throughout the drainage system. Many domes here probably have buried hills as cores.

ARTHUR BEVAN

A Recent Volcanic Eruption near Lassen Peak, California. By HOWEL WILLIAMS. "University of California Publications, Department of Geological Science," Vol. XVII, No. 7, May, 1928. Pp. 22; figs. 9.

This is an account of a rather unusual deposit, a "torrential volcanic breccia," which exists on the north slope of Lassen Peak. The partial collapse of an 1,800-foot spine of dacite upon moistened tuff at its base caused an avalanche of 150,000,000 cubic yards of material. The phe-

nomenon was intermediate between a rock stream and a mud flow. The deposit is a "chaotic assemblage of gigantic, loose, angular blocks" in a matrix of finer débris. It has been interpreted as morainic because of the sharp arcuate ridges and abrupt borders. It was probably formed about two hundred years ago. Excellent photographs are given.

ARTHUR BEVAN

Fusulinidae of North China. By JONQUEI S. LEE. Geological Survey of China, *Paleontologica Sinica*, Series B, Vol. IV, Fascicle 1. Peking, September, 1927. Pp. 172; pls. 24; text figs. 21.

The Fusulinidae of the Pennsylvanian System in Nebraska. By CARL O. DUNBAR and G. E. CONDRA. *Nebraska Geological Survey Bull. 2.* Second Series. Lincoln, Neb., December, 1927. Pp. 135; pls. 15; text figs. 13.

Lee's monograph on the Fusulinidae antedates Dunbar and Condra's publication on the same family by several months, but apparently it was not received in this country until after the latter was issued. Here, then, we have the anomaly of an embarrassment of riches, for the almost simultaneous publication in distant cities of these two important contributions has, of course, made it impossible for either research to have profited from the results of the other. There has been, moreover, a certain unavoidable amount of overlapping in these publications which subsequent workers will have to take into consideration, as well as omissions which might have been remedied had the writers been aware of each other's work. Because of this essential contemporaneity of issue and the semi-identity of subject material, it is almost impossible to discuss the one research to the total exclusion of the other; hence, they are here reviewed together.

Lee's studies are frankly preliminary. In the partially completed second volume, which is to deal with the Fusulinidae of South China, he promises to discuss all biologic and stratigraphic questions dealing with the family, and to propose a complete and natural classification of these protozoans. The present paper has been published in advance, because the Fusulinidae of North China may be regarded as a faunal unit, and because the information is hoped to be of service in coal prospecting and mining in that area.

Lee describes 6 genera of Fusulinidae, comprising 45 species and 16 varieties. Of these, 1 genus, 15 species, and 6 varieties are described as new. The graphic method of delineating species, first utilized by Lee in 1923, is again employed advantageously in a number of cases, and an

attempt obviously has been made to have all of the descriptions exhaustive as well as exact. In these descriptions, unfortunately, Lee used generic terms such as *Girtyina*, *Neofusulinella*, and *Schellwienia*, which Dunbar and Condra have shown fairly conclusively should be regarded as synonyms.

The species from North China are found to be identical with or closely related to those of the Russo-Arctic region, whereas forms suggestive of the Salt Range fauna are said to be very rare, or entirely missing. On the other hand, the Fusulinid fauna of South China belongs entirely to the southern or Indo-Chinese province, whose boundary with the northern province is approximately coincident with the long east-west range of Tsinling.

On the basis of the foraminiferal evidence, Lee has subdivided the great Taiyuan group, or coal-measures of North China, into three series. To the upper he has given the name Shansi series. These beds are almost entirely clastic, and so far as is now known they do not contain any foraminiferal limestones. In some places a fairly thick coal seam occurs. These strata are regarded as Permo-Carboniferous or early Permian in age. The term Taiyuan is now restricted to the middle series, which is made up of clastic deposits interstratified with marine limestones which carry a prolific "*Schellwienia*" fauna. There are numerous thin coals, and in many places there is an important thick layer at the base. The age of the beds is considered to be late Carboniferous, and the fauna is regarded as Ouralian. The lower, or Penchi series, is composed of terrigenous deposits which rarely include thin coals, but which have intercalated with them in most places marine limestones which contain many specimens of "*Fusulinella*" and "*Girtyina*." This fauna is definitely older than that of the overlying beds, and is distinct from it. On the basis of the fossil evidence the Penchi series is regarded as being Moscovian in age.

Lee maintains that there is absolutely no connection between the Fusulinid faunas of Southwestern United States and those of North China. Unfortunately, he apparently was unaware of the work of Beede and Kniker (1924), for he lists as a common North China species, abundant in the Hsinho fauna of Kansu, *Schwagerina fusulinoides*, which the before-mentioned American writers have found in the lower Permian of west Texas. This species, although Permian in North America, is, if Lee is correct in his interpretation, lowest Ouralian in North China, and it is probably somewhat higher Ouralian in the Carnic Alps, from which area it was first described. The essentially world-wide distribution of this species is unique and makes it of great importance. If the horizon in

which it occurs in west Texas is definitely Permian, and the Kansu occurrence is early Ouralian, then it seems quite certain that the species migrated to the present Alpine district and to Southwestern United States from an Asiatic center of dispersal. Beede, however, is of the opinion (1924) that the first appearance of the genus *Schwagerina* may be used as a valid criterion for the inception of early Permian time, and in spite of important obstacles, he has presented considerable evidence to support his view. It obviously follows that Beede's generalization is not universally applicable, or that Lee is wrong concerning the age of the beds carrying *Schwagerina fusulinoides* in North China. The latter seems entirely unlikely since the strata in question are overlaid by other beds with a definite Ouralian fauna.

Dunbar and Condra's admirable publication purports to deal with the Fusulinidae of Nebraska, but in actuality it is a comprehensive study of the entire family with especial reference to the forms found in the central western states. In it there are considered 4 genera, 18 species, and 3 varieties, of which 6 species and 2 varieties are described as new. The description of species, however, is only incidental when compared with great value of the other divisions of the research. These deal with the morphology of the shell, anatomical terminology, methods of study, classification, and stratigraphic distribution.

The thirty-odd pages dealing with the shell morphology easily represent the most important section of the book. The previously known facts have been well marshaled, and the new information is most clearly stated. The glossary of anatomical terms is much more complete than any given heretofore, and this, with the table which shows the different terminologies that have been employed in important previous papers on the Fusulinidae, will be invaluable to all paleontologists. In this table, Lee's 1927 terminology, of course, is not represented. "Osseum," "tectorium," and "annuli" are used by that writer where Dunbar and Condra employ, respectively, "keriotheca," "secondary deposit," and "chomata." Workers may prefer Lee's terms to their synonyms, but, for the sake of uniformity, the reviewer hopes some standard terminology such as that of Dunbar and Condra will be universally adopted. The description of the method of study, as well as the review of previous classifications, will be greatly appreciated by students of the Foraminifera. The new classification proposed is the best yet offered for the Fusulinidae, but future work will doubtless emend it.

In the Mississippi Basin province, three distinct faunal zones have been recognized. These are in descending order, (1) the *Fusulina s.s.*,

and Schwagerina zone, which includes the Upper Wabaunsee formation and the Lower Permian; (2) the *Triticites zone*, essentially, but not exactly, coextensive with the Missouri series; and (3) the *Fusulinella zone*, which is equivalent to the Des Moines series of Nebraska, the Pottsville and Allegheny groups of the Appalachian region, and to the Canyon and Strawn groups of Texas. By comparing this scheme of zoning with that used by Lee for North China, it becomes quite apparent that the Penchi and Taiyuan series are roughly the equivalents of the Des Moines and Missouri series, respectively, and that the Shansi series is Lower Permian, perhaps, but not Permo-Carboniferous.

The plates in both publications are uniformly good, and the style of writing, particularly in the American publication, is excellent. Into both works, however, a few grievous errors of spelling have crept. Dunbar and Condra might have used the graphic scheme of species representation to advantage in some cases, but they apparently overlooked Mlle Colani's valuable paper on this subject, and do not give the method as described by Lee (1923) any consideration. Lee's present publication suffers from the lack of an Index and has a rather inaccurate Table of Contents, whereas Dunbar and Condra's Index is entirely too much abridged. These, however, are minor matters. The writers are to be congratulated on their important contributions, so lucidly written.

Lee's second volume and Dunbar's promised paper on the Fusulinidae of the Cordilleran province are consequently awaited with great interest. We may expect the results of the forthcoming researches, when dovetailed with those of the present publications, to be of great importance in solving some of the difficult problems of late Paleozoic paleogeography.

CAREY CRONEIS

Analytical Principles of the Production of Oil, Gas, and Water from Wells. By STANLEY C. HEROLD. Stanford University, Calif.: Stanford University Press, 1928. Pp. xviii+659; figs. 223. $7.50.

This work is essentially a mathematical and physical treatment of the laws governing the movements of liquids and gases in porous reservoirs, a subject of great interest to a large number of geologists. It is divided into four parts, the first of which (104 pages) very properly treats of elementary principles. Production from wells is taken to depend on three major factors or types of control: hydraulic, involving constant pressure; volumetric, decreasing pressure; and capillary. In the three remaining parts of the book each of these is discussed at length; the longest section

(188 pages) is devoted to the last. In detail are given the methods of analyzing the available data to determine which factor is of major importance in any given pool. If the assumptions made are true under any set of actual field conditions, and providing the deductions offered can be applied by the production engineer, the book with its ten appendixes should be of great value in the application of scientific theory to petroleum production and conservation.

Others besides production engineers will be interested in certain portions, which ones perhaps can be determined best by reading the summary by Ernest K. Parks (pp. 589–97). Quotations cognate to the material covered head the chapters and add to the scholarly appearance. The physical makeup is all that can be desired.

D. J. FISHER

The Geology of Malayan Ore Deposits. By J. B. SCRIVENOR. London: Macmillan & Co., Ltd., 1928. 8vo. Pp. xv+206; figs. 47; pl. 1 large, folded; maps 1 large, colored, folded, and 1 large, black and white, folded. 16*s.* net.

This book is divided into an introductory chapter giving a brief geological sketch of Malaya and the distribution of its ore deposits, five descriptive chapters on the ore deposits, two summary chapters, and a Bibliography. In the Introduction the author evaluates the importance of the main mineral products, namely, gold, tin, and tungsten, and shows how the present production of gold, although still quite important (being one-half that of 1897, which was the record year), has become eclipsed by the production of tin. The author also briefly reviews the historical background of mining on the peninsula.

In the general geological sketch the author points out the distribution of tin and tungsten in two parallel bands, known as the "western" and "eastern" tin belts, and the occurrence of gold in the central belt. The following chapters deal with the gold, tin, and tungsten deposits in more detail. The two chapters headed "Non-Detrital" and "Detrital Deposits" serve to summarize the various occurrences, and to give the reader a more general picture of the situation.

It is clear that the author knows his subject thoroughly from personal experience and an acquaintance with the field. He does, however, fail to organize his discussions of the individual deposits so as to make his material interesting, and in some instances, because of lack of clarity, the scientific value of his material is lost. In many discussions it is not

possible to determine whether the deposit being discussed is magmatic or alluvial. To a reader not familiar with Malayan geography the book is also hard to read, because of the numerous references to local and minor places. Many cumbersome, although intensely interesting, references to local color and history also help obscure the author's main purpose according to the title—*The Geology of Malayan Ore Deposits.*

There is no doubt that such a book as this is of high value to Malayan mining people, and it probably represents the best treatise of the subject to date.

ROBERT E. LANDON

The Oil-Shales of the Lothians. 3d edition, 1927. By R. G. CARRUTHERS, W. CALDWELL, E. M. BAILEY, and H. R. J. CONACHER. Figs. 75; plates 12. 5*s.* 6*d.*

This memoir, which has already passed through two editions since 1906, contains a description of the geology of the oil-shale fields of the Lothians and Fife, and a complete account of the methods employed in mining and retorting the shales and in refining the crude oil. The present edition follows the lines of the two earlier ones but contains much new material in addition.

R. T. C.

The Geology of Portions of the Kimberley Division, with Special Reference to the Fitzroy Basin and the Possibilities of the Occurrence of Mineral Oil. By T. BLATCHFORD. *Western Australia Geological Survey, Bull. 93.* Perth, 1927. Pp. 56; maps 8.

The portion of Australia studied is very little known. Reconnaissance work has shown the presence of thick Lower and Middle Cambrian, Carboniferous, and Jurassic, and thin Pliocene deposits. Petroleum possibilities have been found to be very poor. Maps of parts of the area are inclosed in the report.

C. C. B.